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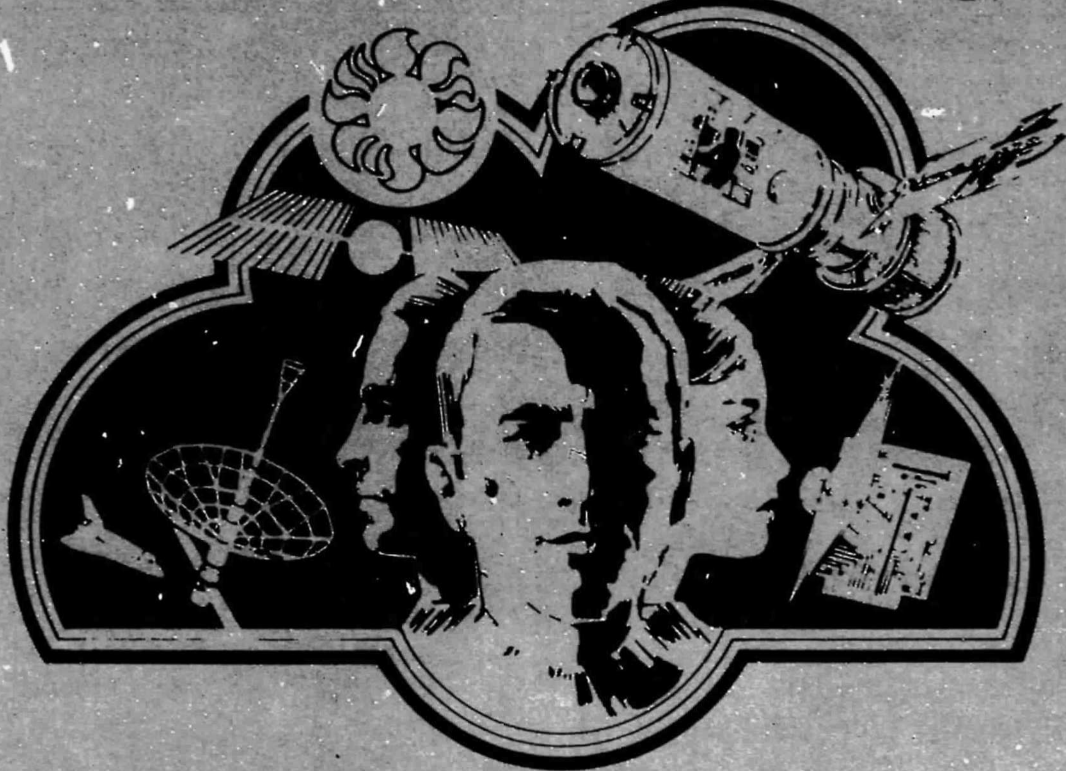

SPACE STATION SYSTEMS ANALYSIS STUDY

PART 2 FINAL REPORT

VOLUME 2
Technical Report

(NASA-CR-151226) SPACE STATION SYSTEMS ANALYSIS STUDY. PART 2, VOLUME 2 Final Report (McDonnell-Douglas Corp.) 251 p HC A12/MF A01 CSCL 22A

N77-19136

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G3/15 20562

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

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APPROVED BY: C. J. DaRos
C. J. DaROS
STUDY MANAGER, SPACE STATION STUDY

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST
5301 Bolsa Avenue, Huntington Beach, CA 92647

PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a manned space facility capable of orderly growth with regard to both function and orbit location. The study activity has been organized into three parts. Part 1 was a 5-month effort to review candidate objectives, define implementation requirements, and evaluate potential program options in low earth orbit and in geosynchronous orbit. It was completed on 31 August 1976 and was documented in three volumes (Report MDC G6508, dated 1 September 1976).

Part 2 has defined and evaluated specific system options within the framework of the potential program options developed in Part 1. This final report of Part 2 study activity consists of the following:

- Volume 1, Executive Summary
- Volume 2, Technical Report
- Volume 3, Appendixes
  - Book 1, Program Requirements Documentation
  - Book 2, Supporting Data
  - Book 3, Cost and Schedule Data

The third and last portion of the study will be a 5-month effort (February to June 1977) to define a series of program alternatives and refine associated system design concepts so that they satisfy the requirements of the low earth orbit program option in the most cost-effective manner.

During Parts 1 and 2 of the study subcontract support was provided to the McDonnell Douglas Astronautics Company (MDAC) by TRW Systems Group, Aeronutronic Ford Corporation, the Raytheon Company, and Hamilton Standard.

Questions regarding the study activity or the material appearing in this report should be directed to:

Jerry W. Craig, EA 4
Manager, Space Station Systems Analysis Study
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 70058

or

C. J. DaRos
Study Manager, Space Station Systems Analysis Study
McDonnell Douglas Astronautics Company-West
Huntington Beach, California 92647
Telephone (714) 896-1885

CONTENTS

Section 1
INTRODUCTION

The progress of space technology has permitted space activities to expand from the early exploratory steps of the 1960's to the realization of the cost-effective applications of the 1970's. The economic benefits derived from communication satellites in providing global communication networks and from meteorological satellites in improving the range and accuracy of weather forecasts have been amply demonstrated.

The anticipated reduction in the cost and complexity of delivering payloads to space as provided by the Shuttle Transportation System, currently under development, can mark the beginning of a new era in the exploration and use of space. To fully exploit this potential in the 1980's and beyond, increasing use of manned facilities can be anticipated. The rich heritage of manned space experience culminating in Skylab and Apollo-Soyuz when combined with the flexibility of the Shuttle, can provide the mechanism for investigating, understanding, and solving many of the critical problems which we and the rest of the world will face in the next 50 years. The growth path will progress from the limited-duration Shuttle and Spacelab missions to permanently manned stations. Initially these stations can be assembled from modular units delivered by the Shuttle and can grow the size and complexity to provide construction bases for the large public service communication antennas, for new energy systems, and for the industrial applications of the future.

The fact that this capability can be developed does not establish the fact that it will be, nor does it determine when it should be developed. Priorities depend on changing political, economic, social, and technological factors.

The purpose of this study is to provide information to NASA program planners which can help resolve the difficult problems of apportioning limited resources

among an almost unlimited number of candidate projects—and in so doing, to provide a sound technological base capable of developing and preserving the options open to our nation in the decades to come. The course to be charted requires long range planning to ensure that fiscal commitments will be met and that required systems and components will be available when needed. At the same time there must be flexibility of allowing modifications as constraints and objectives change.

Section 2
SUMMARY

During Part 2 of the study, selected program options derived during Part 1 activities were analyzed and configuration concepts (Space Station System Options) were developed. Supporting effort defined in greater detail the requirements of certain of the objective elements that are contained in the program options. Analysis of mission operations and derivation of transportation requirements for the selected options complemented this study effort. In addition, potential schedule and funding requirements were determined for each system option. Figure 2-1, presents the study schedule and indicates past accomplishments together with current plans and status.

2.1 SPACE STATION SYSTEMS ANALYSIS APPROACH

The Space Station Systems Analysis Study has drawn on the broad data base gathered from prior operational and study programs. The study uses a system engineering approach to ensure full utilization of these background data and key criteria to evolve preferred Space Station concepts. So that these concepts will provide a firm base for future program plans, the activities of this Phase A study are designed to provide implementation plans and preliminary specifications suitable for Phase-B entry. This approach allows early identification of the design and development steps required by the most promising future programs.

The potential evolution in space capabilities for the next two decades is shown in Figure 2-2. Expendable launch vehicles will phase out as the Shuttle becomes operational. The Shuttle-Spacelab combinations will be the basis for space research and operations throughout the 1980's. More ambitious undertakings (requiring larger sizes or longer stay times) will require a Space Station. Early results can be obtained from Shuttle-sortie and Shuttle-tended concepts, with more extensive operations following in a permanently manned station.

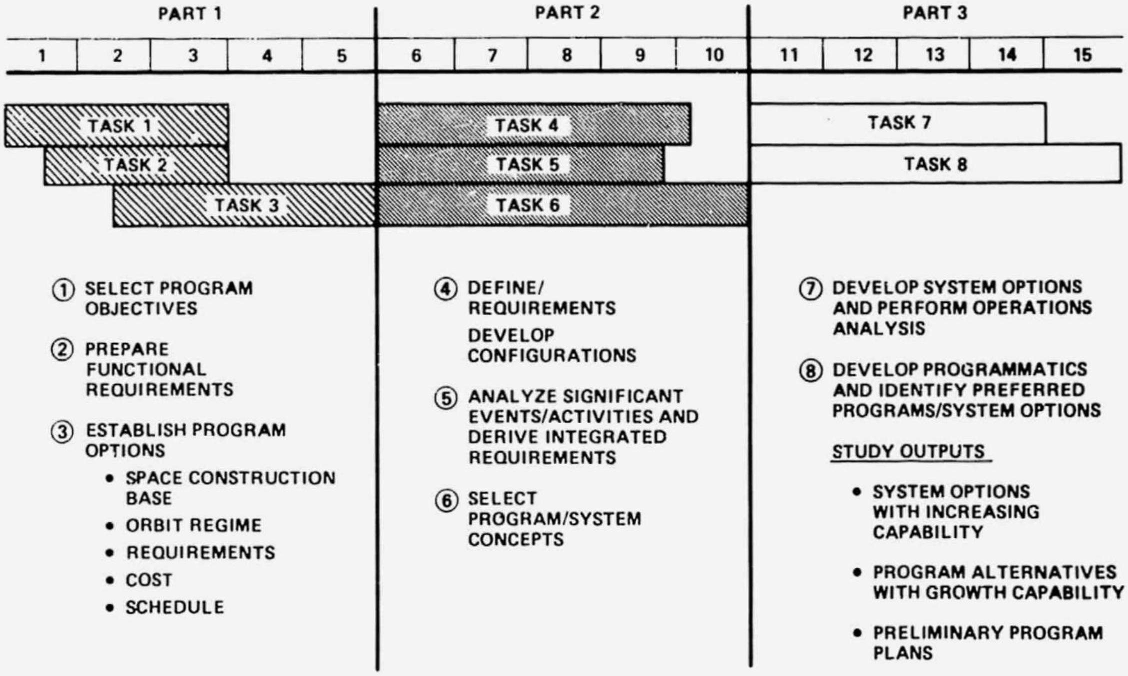

Figure 2-1. Space Station Study

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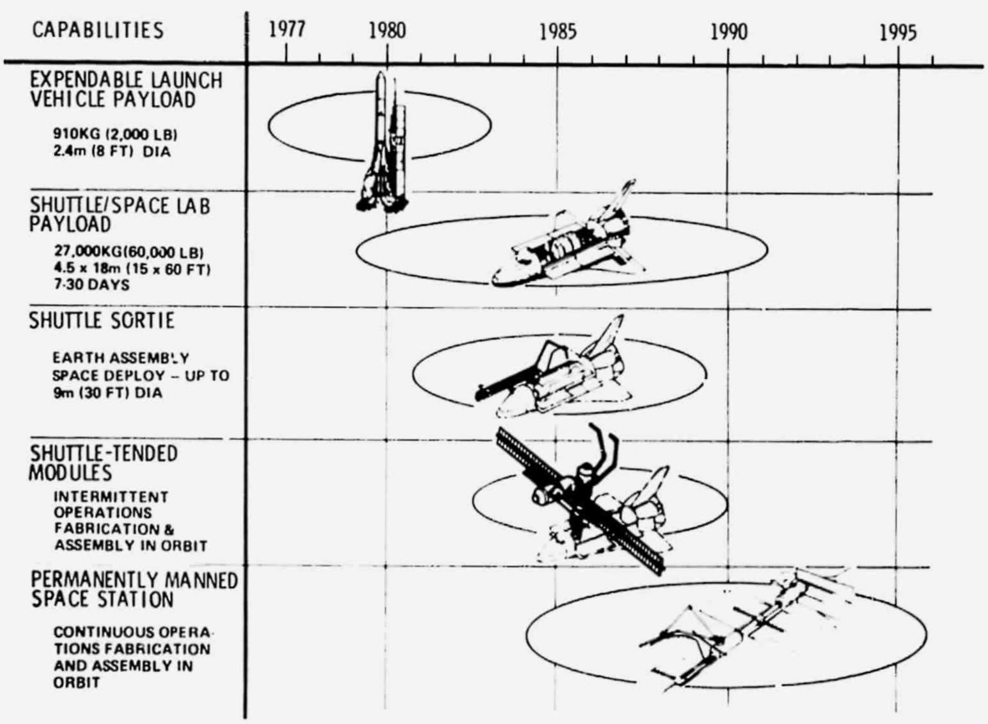

Figure 2-2. Space Program Evolution

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During Parts 1 and 2 of the study, the following steps were accomplished:

1. Identification of 61 objectives
2. Definition of 9 selected objectives in greater depth
3. Screening of objectives
4. Identification of 45 program options (combination of the 9 objectives)
5. Selection of 4 program options for further study
6. Synthesis of system elements into program options
7. Definition of program/system selected options

Step 7 provided a definition of program/system options to be studied in depth during Part 3, subsequent to NASA review/agreement.

Of the objectives defined to date, most can be accomplished fully only by extended manned activities in orbit. Manned support is necessary over the full spectrum of objectives: construction and assembly of the stations required for the Solar Power System (SPS) and earth services; establishment of commercially oriented space processing and production methods; and participation and support in various other space operations ranging from laboratory R&D to support of planetary explorations.

2.2 DEFINITION AND SELECTION OF PROGRAM OPTIONS

In Part 1 of the study, 45 program options were defined. The emphasis at that time was to develop options that covered reasonable combinations of objective elements, required a broad range of program costs, covered the various orbit regimes of interest, and included growth elements such as the heavy-lift launch vehicle (HLLV) and orbital transfer vehicles (OTV's). In short, the intent was to bound the possibilities and present a wide range of choices.

A systematic evaluation of the options was performed. This system engineering approach utilized four independent evaluation criteria (illustrated in Figure 2-3) as a means of discriminating one option from another. The first criterion is level of achievement, defined as the percentage of the total number of objective elements included within a particular option. It covers a range of 45% to 95% over the entire population of 45 options.

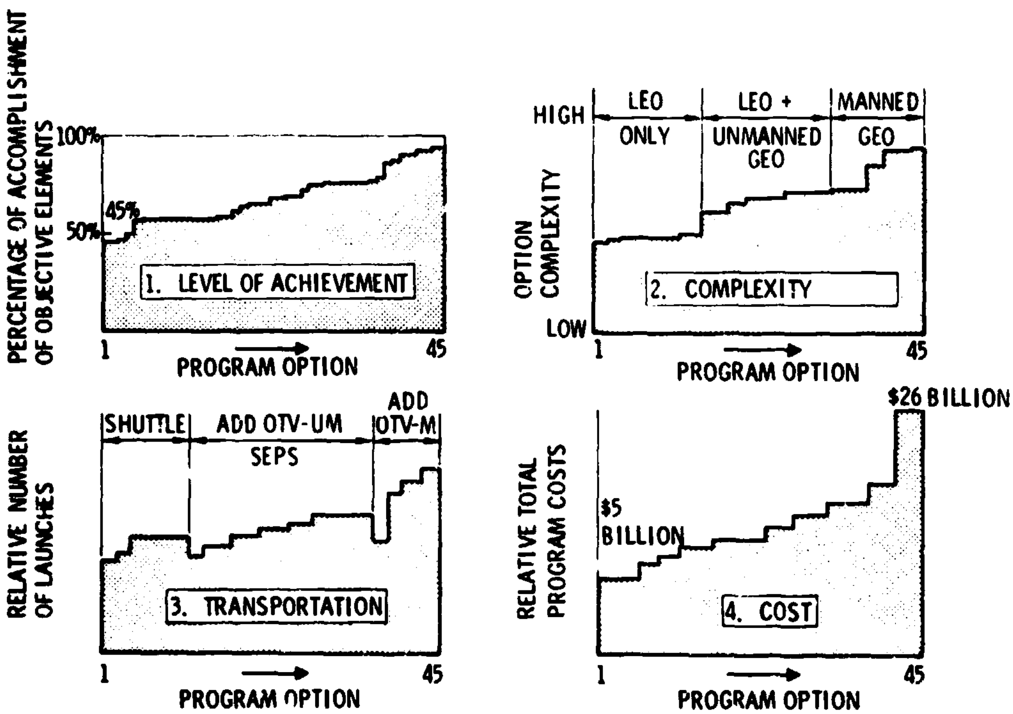

Figure 2-3. Program Option Categorization Criteria.

The second criterion complexity is a subjective evaluation of the options. The LEO-only region shows those options that are confined entirely to low earth orbit. The LEO plus unmanned-GEO region shows those options that include the operation of unmanned elements in geostationary orbits that had previously been constructed or assembled in LEO. The manned GEO region shows those options that involve manned operations in GEO, either in the construction of hardware or to support testing.

The third criterion, transportation, is defined as the relative number of launches required to support the options. The fourth and last criterion, cost, is the total relative program cost for the 45 options, the low value being about $5 billion, and the high about $26 billion.

The study revealed that the four-fold categorization scheme was most helpful in distinguishing the similarities and differences among the options. It was also possible to identify general classes of options (e.g., those restricted to operations only in low earth orbit). As a result, a selection was made of

nine program options as being representative of the entire population. From these nine a final selection was made with the concurrence of NASA.

Four program options were selected for further definition and contain, in various combination, the 21 objective elements delineated in Table 2-1. The content of each option examined is shown in Table 2-2. These options are defined as: Option L – manned operations limited to low earth orbit (LEO); Option LG1 – manned operations performed in LEO with some test operations of hardware that was constructed in LEO being conducted in GEO; Option LG2 – operations in LEO with some construction as well as test operations performed in GEO; and Option G – manned operations including construction entirely in GEO.

For Program Option L (Figure 2-4) two operational modes have been investigated:

- Early Shuttle-tended operations, during which elements of a permanently manned SCB are used only while the Shuttle is present. Subsequently, when a full SCB is assembled and activated, Shuttle continues to supply logistic support.
- Construction and activation of a full SCB prior to operations.

Either of these modes was found to be viable with a significant cost/schedule advantage for the Shuttle-tended mode.

The Shuttle-tended concept may provide an early space construction fabrication and assembly capability only, or it can be expanded to include space processing development activities. Crew requirements are compatible with the Shuttle support capability of up to seven SCB crewmen. Fabrication and assembly operations require three crewmen for nominal tasks and three crewmen are sufficient to conduct space processing development tasks. The Orbiter pilot and copilot are available to act in the capacity of SCB/Orbiter operational crew.

The permanently manned conceptual approach to the SCB requires two crew accommodation modules and a logistics module in addition to those required by the Shuttle-tended configuration. In this operational mode, the crew is continuously available, with rotation taking place on 90- to 180-day periods. During the initial operational phase, a single power module and solar array would

Table 2-1

OBJECTIVE ELEMENTS FROM PART 1

1. Solar Power System (SPS)
   - A. $\boxed{\text{Test Article-1}}$
   - B. $\boxed{\text{Test Article-2}}$
   - C. Test Article-3
2. Earth Services
   - A. $\boxed{\text{30,}}$ 100, and 300m radiometers
   - B. $\boxed{\text{Multibeam lens antenna}}$
   - C. 3.75 km navigation antenna
3. Space Processing (SP)
   - A. $\boxed{\text{Development}}$
   - B. $\boxed{\text{Optimization}}$
   - C. Commercial Production
   - D. SI Ribbon/blanket plant
4. Multidiscipline Laboratory (MDL)
   - A. Minimum level
   - B. Maximum level
5. Living and Working in Space (LWIS)
   - A. Limited research
   - B. Extensive research
   - C. Demonstration of techniques
   - D. Construction support
6. Orbital Depot
   - A. R&D for LEO – GEO transport system
7. Space Cosmology
   - A. Component R&D
   - B. MK II Radiotelescope
8. Sensor Development and Test
   - A. Development and test
   - B. Fabrication and evaluation

$\boxed{}$ Indicates objective elements that received special emphasis during Part 2 of the study

Table 2-2

OBJECTIVE ELEMENT CONTENT OF PROGRAM OPTIONS

Objective Elements	Program Options Examined			
	L	G	LG1	LG2
1A. SPS Test Article-1	X	X	X	X(1)
1B. SPS Test Article-2	X		X	X(1)
1C. SPS Test Article-3			X(1)	X(2)
2A. 30, 100, and 300m radiometers	X		X(1)	X(2)
2B. Multibeam lens antenna		X	X(1)	X(2)
2C. 3.75 km navigation antenna			X(1)	X(2)
3A. Space processing development	X		X	X
3B. Space processing optimization	X		X	X
3C. Commercial process plants			X	X
3D. Silicon Ribbon/blanket plant			X	X
4A. Minimum level MDL	X			
4B. Maximum level MDL	X			
5A. Limited research LWIS	X		X	X
5B. Extensive Research LWIS	X			
5C. Demonstration of techniques	X	X	X	X
5D. Construction support	X	X	X	X
6A. Orbital depot R&D			X	X
7A. Space cosmology R&D			X	X
7B. MK II radiotelescope			X(1)	X(2)
8A. Sensor development and test			X	X
8B. Sensor fabrication and evaluation			X	X

(1) Construction performed at LEO
(2) Construction performed at GEO

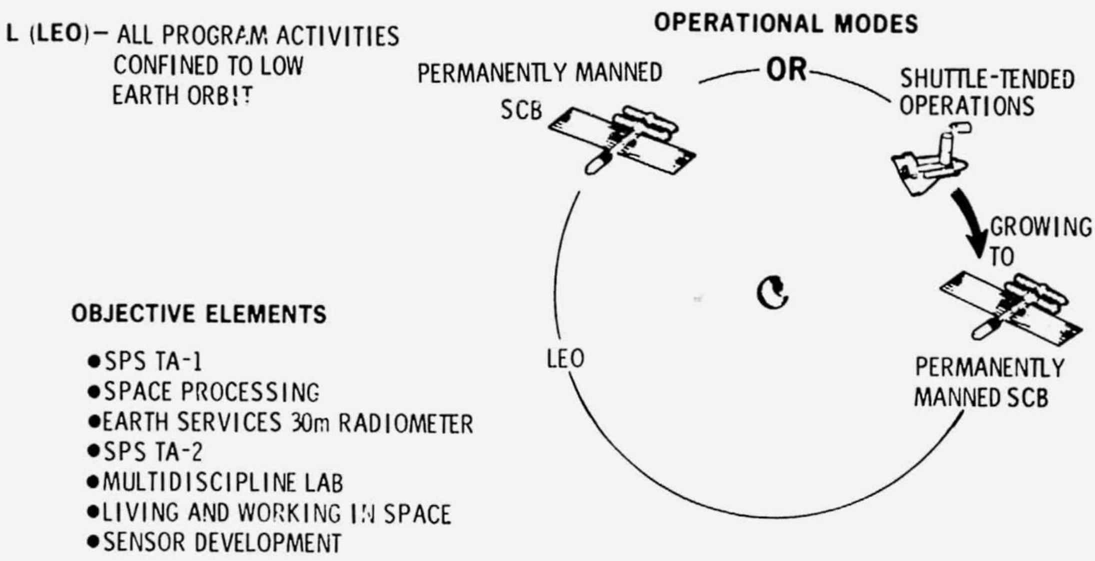

Figure 2-4. Program Option L

supply sufficient power to accomplish a broad spectrum of objectives in space construction (e.g., 30m torus radiometer, SPS TA-1, SPS TA-2, etc.) and space processing. Growth to a 14-man configuration would require additional crew, objective elements and power modules, and would allow simultaneous pursuit of multiple objectives.

Program Option LG1 (Figure 2-5) expands the LEO activities to include construction of large structures in LEO, which are then transported to GEO for test and operations. These activities use an all-up SCB in LEO and an OTV for transport to GEO; manned test and operations in GEO are accomplished by GEO sortie missions or by use of a small Space Station at GEO. As indicated on the figure, all objective element activities are undertaken wholly or in part at LEO, and only those gaining significant advantage from GEO are transferred to that location.

LG1 (LEO-GEO)– ACTIVITIES OF L EXPANDED TO INCLUDE CONSTRUCTION OF LARGE STRUCTURES IN LEO AND THEIR TRANSPORT TO GEO FOR SUBSEQUENT TEST AND OPERATIONS

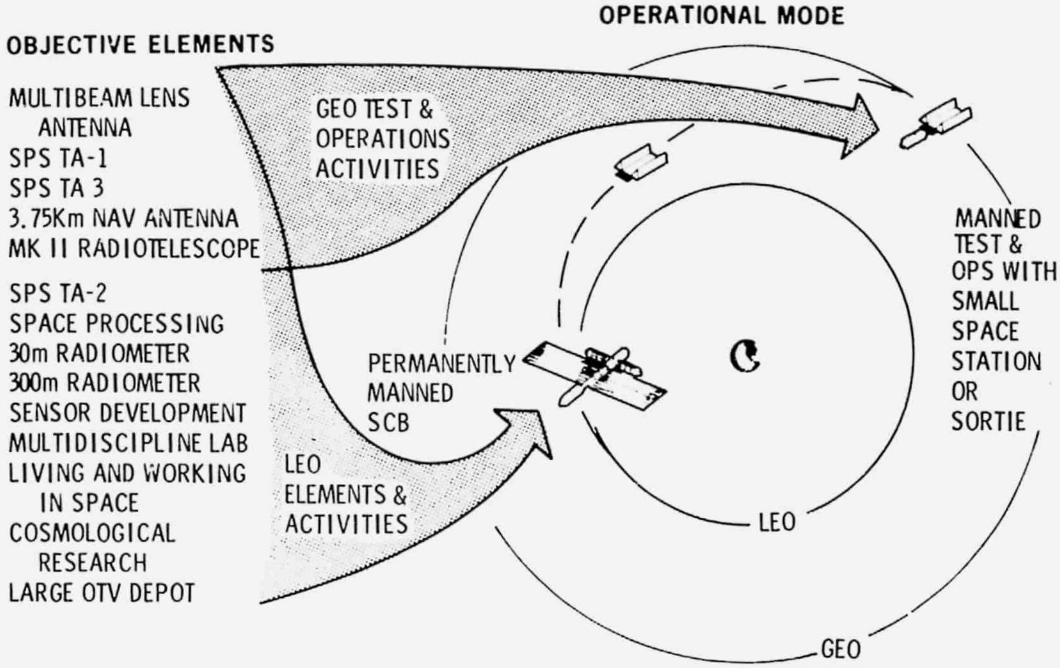

Figure 2-5. Program Option LG1

Program Option LG2 (Figure 2-6) expands on LG1 by providing for the construction at GEO of those objective elements to be used there. This is accomplished by providing a permanently manned SCB at GEO in addition to the one at LEO. Logistics are supported by Shuttle and an OTV.

For Program Option G, all activities are confined to GEO. As indicated, in Figure 2-7, two operational modes have been investigated:

- Early Shuttle-OTV sortie mission support of elements of a permanently manned SCB, supplanted by full, permanent SCB operations.
- Construction and activation of a full SCB in GEO prior to operations.

Although it is a viable option, G suffers from relatively higher transportation costs.

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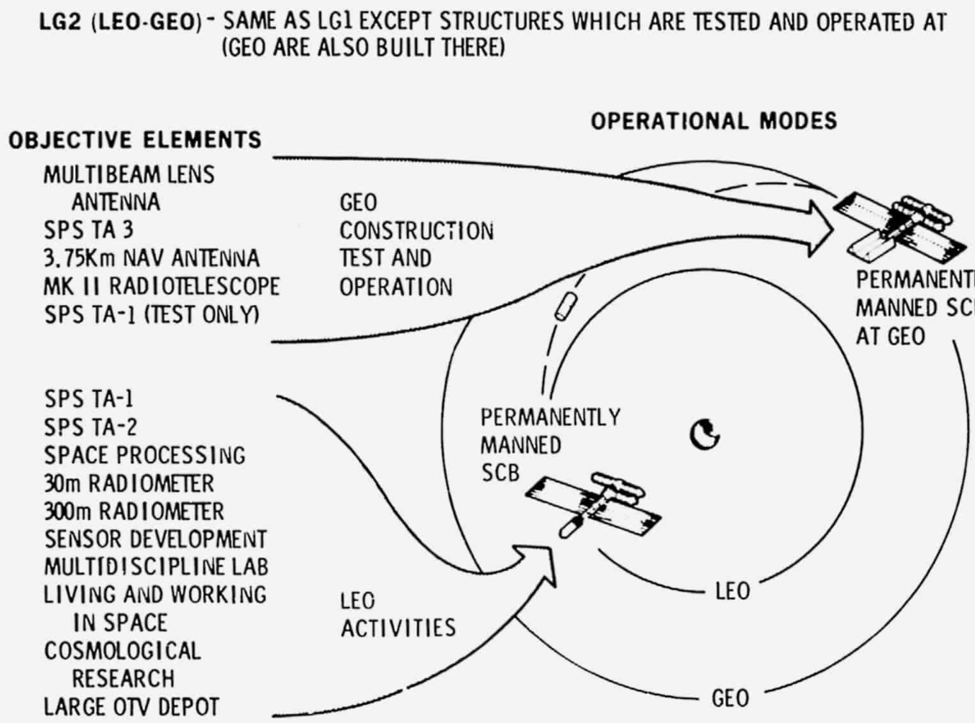

Figure 2-6. Program Option LG2

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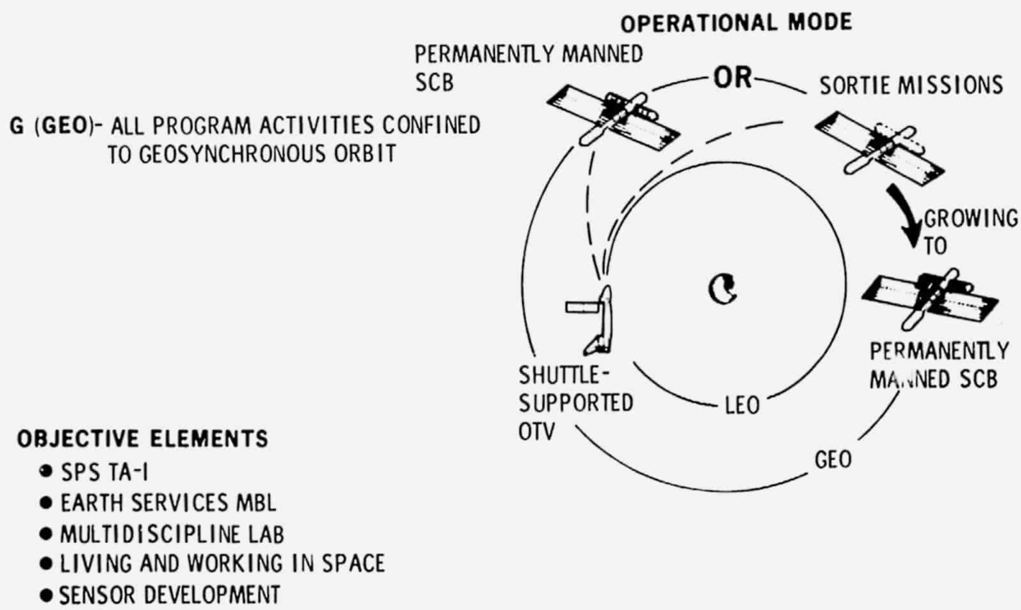

Figure 2-7. Program Option G

2.3 ANALYSIS OF PROGRAM OBJECTIVES

In synthesizing the program options, the objective elements (which are items of flight hardware) are grouped into various potential program options that can be accomplished in orbital operational regimes at LEO, GEO, and combinations thereof. Each of the major program options, in turn, has been divided into subsets based upon the selected operational mode. For example, the initially Shuttle-tended mode grows to the permanently manned SCB within a year or two. In the Shuttle-tended mode, the SCB would operate exclusively in that mode, being manned only when the Shuttle is docked to the SCB.

In this study, each program option is defined as a complete program including the mission hardware and all required transportation system elements. This approach permits direct comparison of accomplishment versus cost for various program options. Figure 2-8 portrays the hierarchy of elements combined into system options. The system options that make up each program option represent different basic concepts in terms of hardware design and operational approach, and are not merely a rearrangement of similar hardware. The system options, selected with NASA agreement, will be the top level elements to be emphasized in Part 3 of this study.

In addition to the synthesis of system options, the program objectives were further analyzed. The functional and operational requirements, as well as the identification of mission hardware elements associated with each objective were defined. The study confirmed that commonality of requirements existed among the objective elements.

The commonality of operational requirements necessary to successfully complete various objective elements results in a desirable synergism in cost savings extended throughout the overall SCB program. In Figure 2-9, major requirements for a particular objective element are indicated by a large check (√); minor requirements by a small check mark (✓). For example, all objective elements require crane operations either to a major or minor extent. Crane operations are a major requirement in the fabrication and assembly of SPS TA-1, TA-2, and a 30m radiometer. In contrast, the laboratory-type

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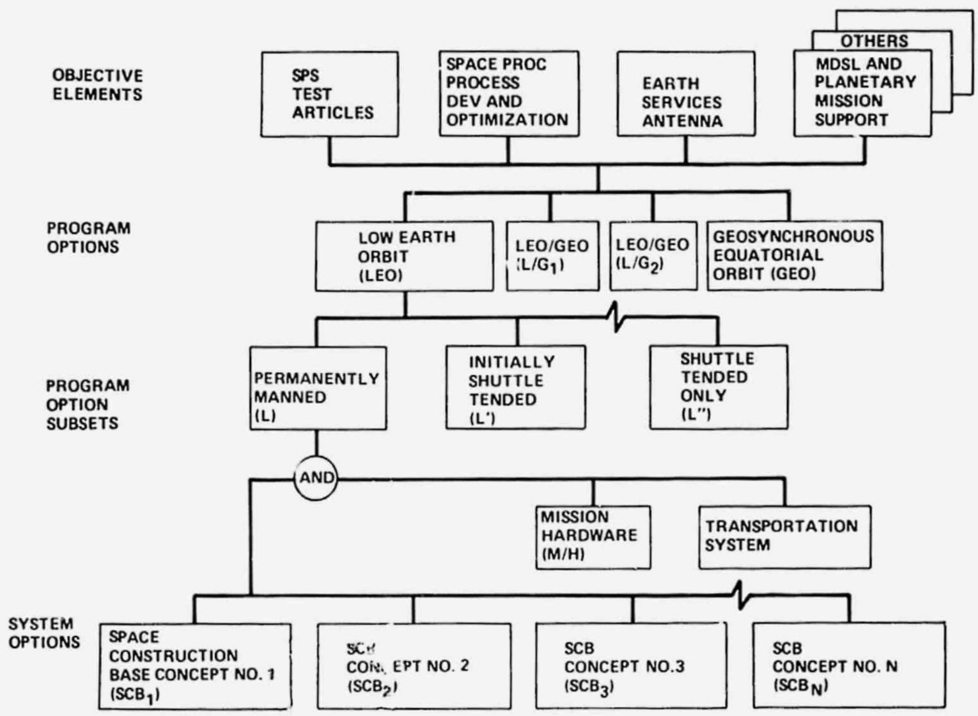

Figure 2-8. Synthesis of Program Options

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OBJECTIVE ELEMENT	CRANE OPERATIONS	SPACE FABRICATION	SPACE ASSEMBLY	EVA REQUIREMENTS	LONG DURATION
TEST ARTICLE-1	✓	✓	✓	✓	✓
TEST ARTICLE-2	✓	✓	✓	✓	✓
30m RADIOMETER ANTENNAS	✓	✓	✓	✓	✓
SPACE PROCESSING	✓				✓
MULTIDISCIPLINE LABORATORY	✓			✓	✓
LIVING AND WORKING IN SPACE	✓	✓	✓	✓	✓
SENSOR DEVELOPMENT AND TEST	✓		✓	✓	✓

Figure 2-9. Several Objective Elements Yield Common Requirements

elements basically necessitate crane operations only initially to position the module or to supply necessary materials. Also, all elements could provide useful functions throughout a long time period, although for the basic laboratory-type objective elements, longer duration operations are more strongly implied than for the fabrication and assembly oriented objective elements. Data to support the living and working in space objective will, of course, be derived from the performance of all operations.

An example of the SCB growth as additional objective elements are accommodated, taking into account common requirements, is shown in Figures 2-10 through 2-13. Figure 2-10 shows a configuration of a Shuttle-tended (i.e., the Shuttle provides on-station support and life support services for the 4- to 7-man fabrication and assembly crew) SCB with limited capabilities. Figure 2-11 shows an advanced version of the Shuttle-tended configuration which could offer growth to the configuration shown in Figure 2-12. Figure 2-13 depicts a permanently manned SCB requiring only logistic support by the Shuttle.

With the addition of the bioprocessing and shaped-crystal processing modules (Figure 2-13), the mass of the station grows to 100,000 kg and the pressurized volume increases to 1,370 m^3. Power requirements at the bus increase from 23 to 34 kW, necessitating a solar array area of 1,250 m^2. To compensate for the increase in power consumption, the radiator area has been enlarged to 480 m^2. Assuming a capability of providing approximately 120 m^2 of radiator surface per module, adequate cooling area is available.

For the 7-man permanently manned Space Construction Base (SCB), the cost estimates to develop, produce, place in orbit, and operate the station elements are given in Figures 2-14 and 2-15. Figure 2-14 presents the annual funding requirements and cumulative costs by government fiscal year. The costs are stated in terms of mid-1977 fiscal year dollars. The costs include DDT&E, Production, and Operation and are segregated by major element, SCB (C), mission hardware (M), and transportation (T).

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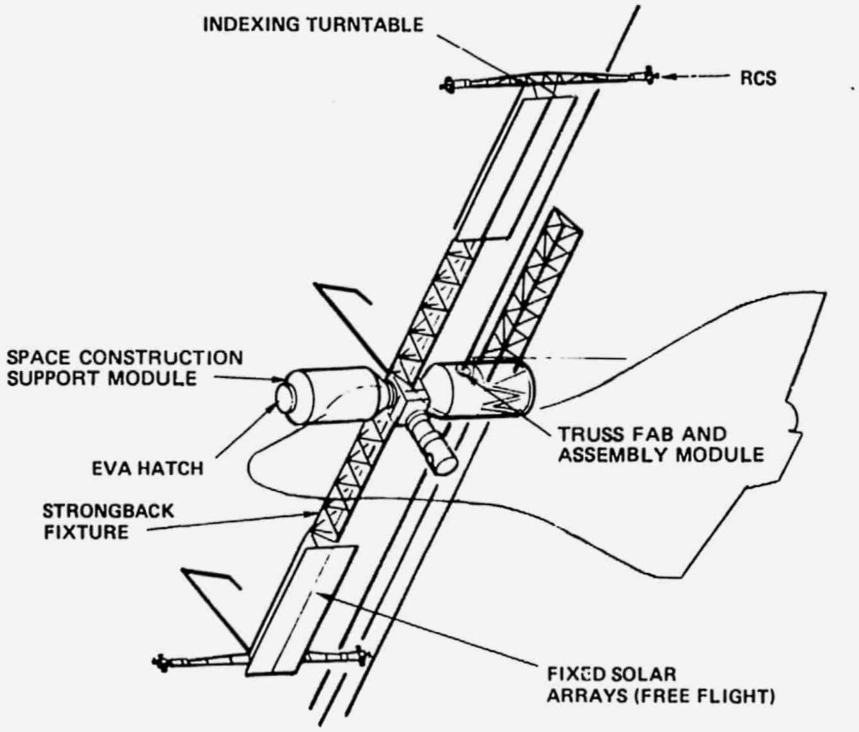

Figure 2-10. SCB (L') Shuttle Tended – Strongback

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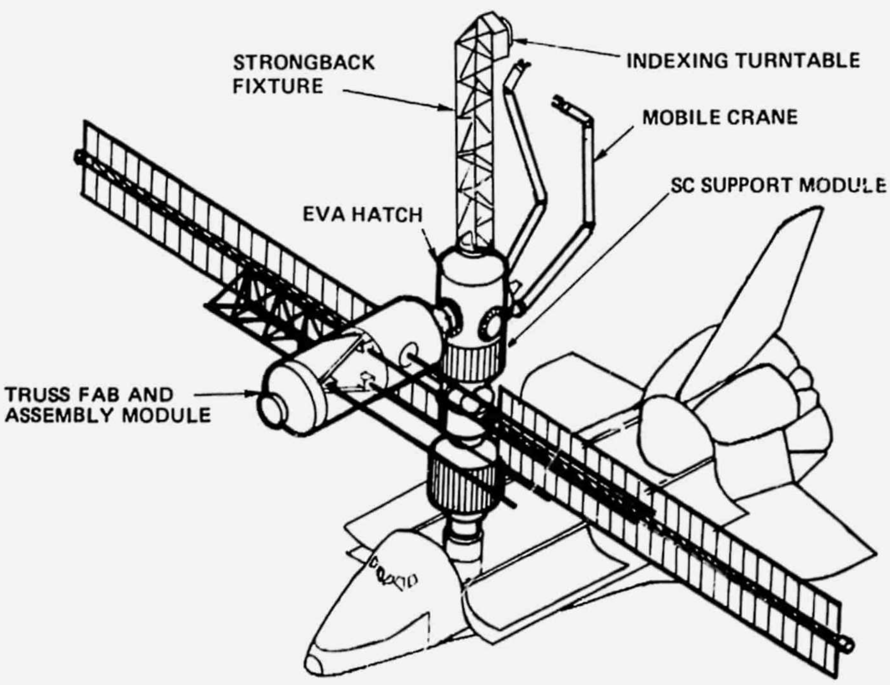

Figure 2-11. SCB (L') Shuttle Tended – Single-Shuttle Launch

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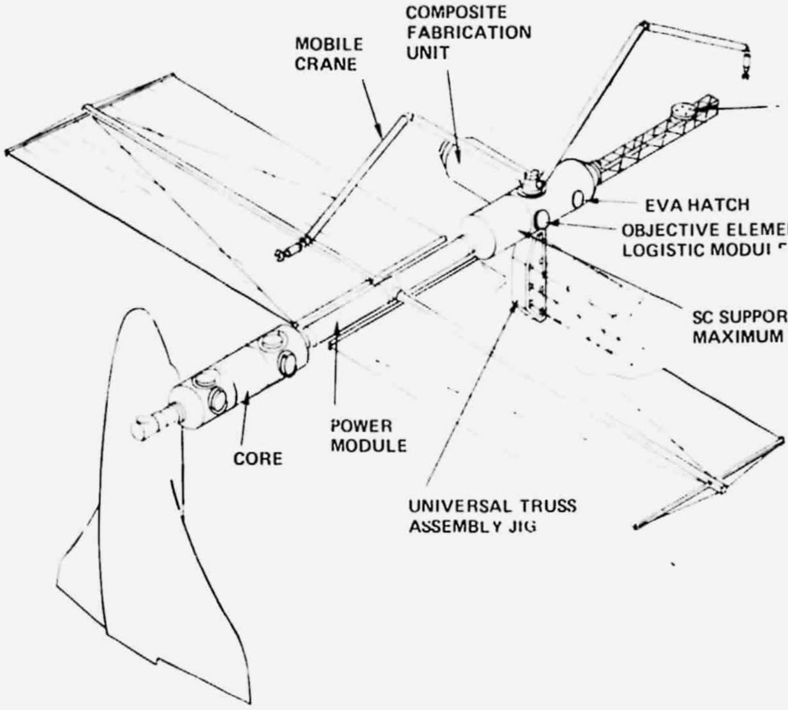

Figure 2-12. SCB (L') Shuttle Tended – Direct Growth

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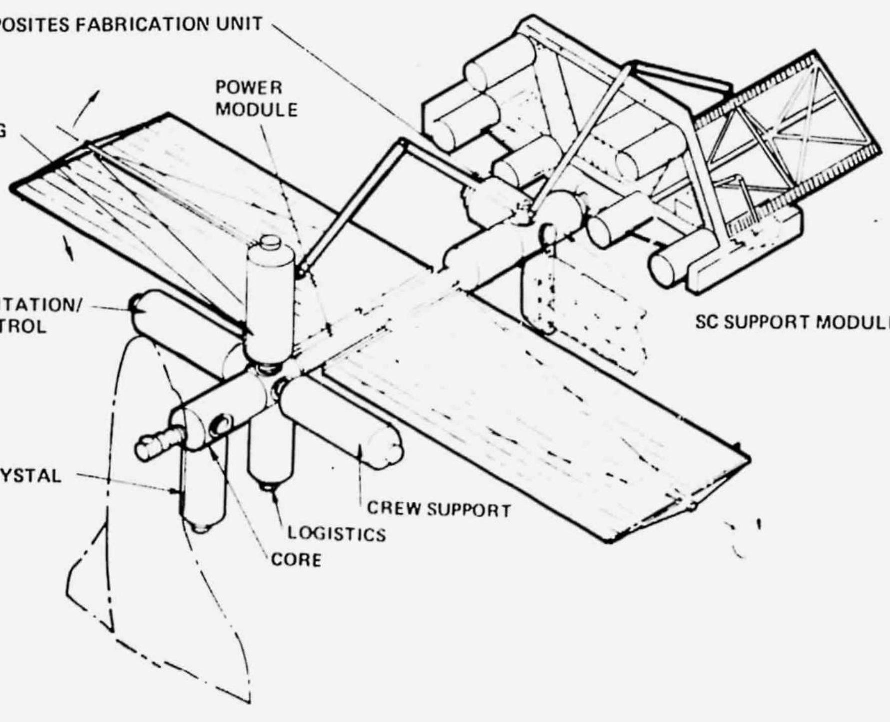

Figure 2-13. SCB (L) Permanently Manned – Direct Growth

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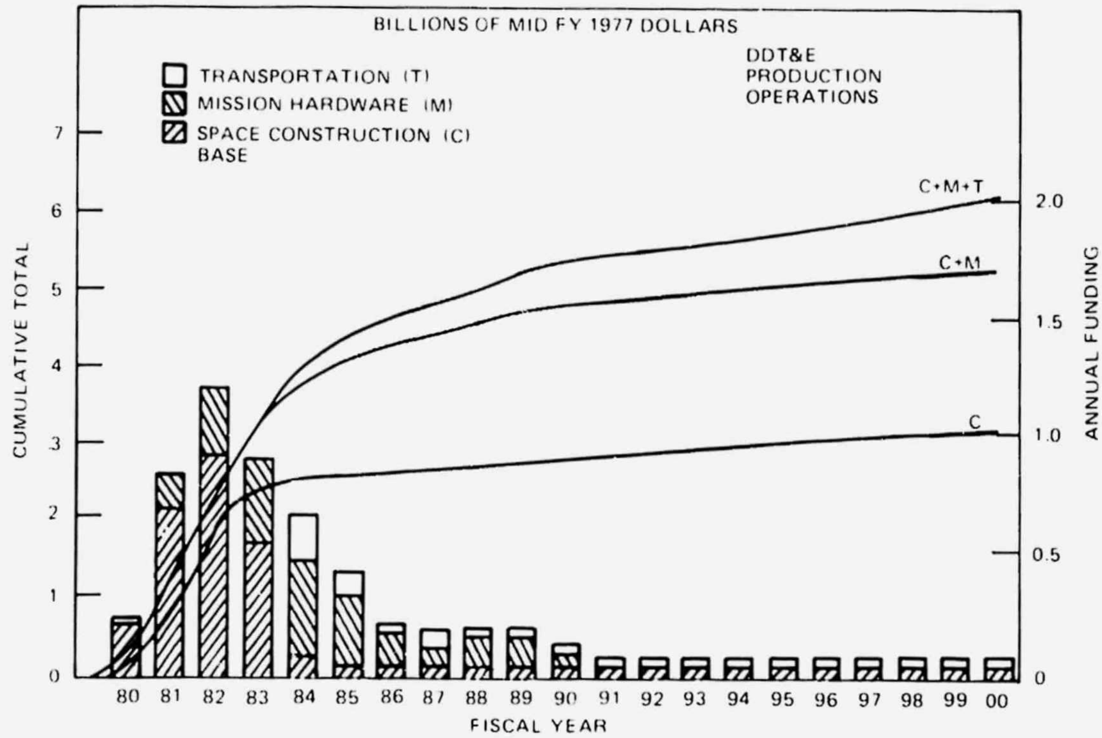

Figure 2-14. Permantly Manned Option Cost

Figure 2-15 presents a breakdown of the cost for each of the three major elements. The SCB is broken down to show the cost of the individual modules that comprise the SCB, and the cost of management and integration, ground test and GSE, and ground support during the operational period. The mission hardware is broken down to show the cost of the individual objective elements. The transportation cost is divided to show the cost required for implacing the SCB and mission hardware into orbit, and the logistics transportation cost for the operational period.

Using Space Station Program Option L objectives as a baseline, the study team investigated the degree to which these same objectives might be accomplished through the currently planned Shuttle and Spacelab programs or through a Space Station which is Shuttle-tended in lieu of being permanently manned.

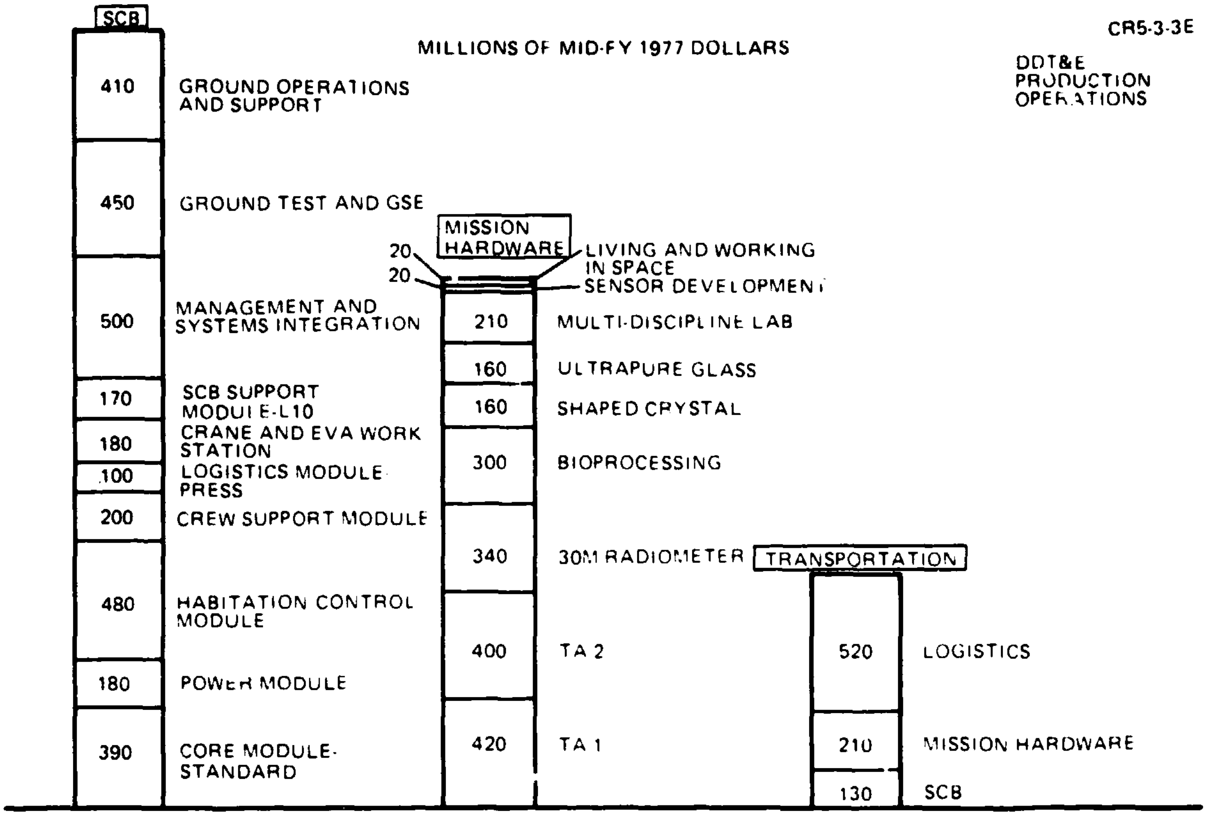

Figure 2-15. Permanently Manned Cost Breakdown

Preliminary conclusions drawn show that the Shuttle-Spacelab missions provide an excellent R&D base, but the long-duration capability of the permanently manned Space Station is needed to accomplish these objectives in a cost-effective manner. At this juncture in the study, the evidence suggests that the 7 to 14-man Space Station provides for satisfaction of the requirements and accomplishment of the objectives in a much more timely and efficient manner than a Shuttle-tended-only option.

2.4 SUMMARY OF FINDINGS

A review of currently proposed NASA mission models and other related mission planning materials indicates that significant progress can be expected during STS-Spacelab missions programmed for the 1980 to 1983 time period. Background data in the areas of space processing, life sciences, physics, astronomy, earth sciences, and space technology, will provide the point of departure for the missions to be defined for the time period beyond 1983.

It can be anticipated that the STS-Spacelab system will not only continue to be operational after 1983, but furthermore, the initial dollar investment in these facilities will have already been made. Accordingly, economic considerations alone would dictate the continued use of the Shuttle-Spacelab whenever feasible. This system can be expected to continue to support short-duration (7 to 30 days) manned operations for many years.

Figure 2-16 summarizes the mission durations, payload weight, crew sizes, power, orbital regimes, and man-hours per year, which can be anticipated for the basic Shuttle-Spacelab system, and for the Space Station. Areas of capability overlap are also indicated. The final program plan developed for the 1980's must achieve an optimal balance of the potential capabilities that will be available.

The capability and cost resources needed to meet the full NASA Space Station program, accomplishing all program objectives that have been established for LEO and GEO operations. Recognizing the realities of budgetary constraints,

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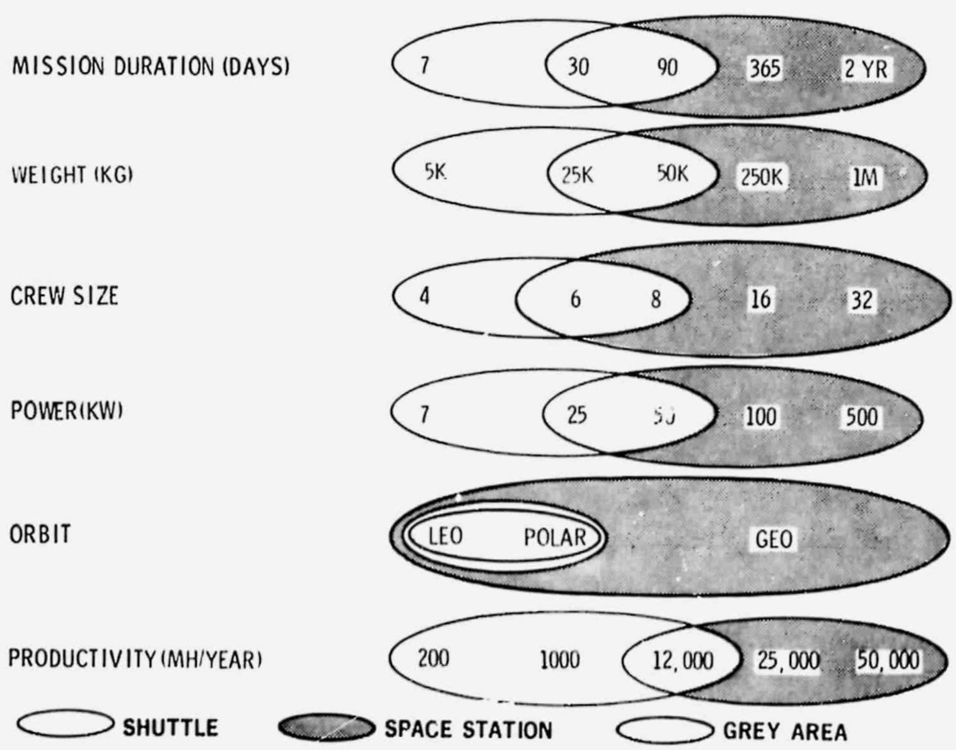


Figure 2-16. Shuttle/Space Station Operating Regimes

a portion of the total program objectives can still be fulfilled using the Shuttle-tended mode of operation as the initial program activity. This mode is predicated on LEO-operation-only, with emphasis placed on SPS and earth services.

In Part 2, several LEO program/system options were defined. These options consider both initially Shuttle-tended and permanently manned concepts. They vary in the crew complement from 7 to 21 men. In addition, program system options with operations in LEO and some test operations in GEO (LG1); operations in LEO with some construction and test operations in GEO (LG2); and all operations in GEO were defined. One of the most promising of the candidate programs begins with a Shuttle-tended SCB in LEO for early operations, and then grows to a permanently manned space facility.

During Part 3 the selected program/system option(s) will be further defined, with major consideration to modularity, build-up sequence and funding.

Briefly then:

Where we are today –

- A large number of objectives have been identified to which an SCB could provide significant support
- A worthwhile series of program options have been examined which span a wide range of funding options
- A low earth orbit program option was chosen for detailed consideration of system options - within this program option an early Shuttle-tended SCB with growth to permanently manned presents most promise

Where we are going –

- The next immediate step is to select the program/system option(s) for use in Part 3
- The next NASA-industry objective should be the development of a modular (low cost) approach to a general-purpose SCB
- This SCB must be designed to support:

  Space construction of test articles (SPS) and antennae (earth services)

  Space manufacturing/processing

  Other supporting objectives
- Design and development activities must recognize realistic budget limitations and must build upon ongoing activities

Section 3
OBJECTIVE ELEMENTS AND REQUIREMENTS

During Part 1 of the study, 10 key program objectives were defined. Two objectives (Nuclear Energy and Cluster Support Base) were not considered promising for early application; therefore, further analysis was deferred during Part 2. Three of the eight remaining objectives (Solar Power System, Earth Services, and Space Processing) were identified as early potential candidates; they were defined in greater depth during Part 2. For each of the eight objectives, sets of functional requirements were derived. The requirements identify specific high-technology items that need development, critical tests that must be conducted, processes and procedures that must be evaluated and developed, and the derivation of a logical sequence in which the technology should be pursued in space (i.e., the substance of a development plan).

Methods of satisfying the functional requirements were then derived. For those objectives that require SCB participation an objective element was defined. Within the context of the study an objective element is defined as a physical facility, equipment item, test apparatus, structural assembly, etc. necessary to perform the required function. As an example, scaled-down "test articles" of an eventual full-scale SPS were defined to satisfy functional requirements involving evaluation of on-orbit fabrication of large structure, microwave power transmission, and environmental effects. These objective elements and requirements imposed on the SCB form the basic set of information necessary to define SCB and related program options.

3.1 SATELLITE POWER SYSTEM OBJECTIVE

The SPS objective is to provide a permanent space test capability for evaluation of the technical and economic feasibility of SPS.

For the SPS objective to be satisfied, the study determined that technical feasibility must first be established. Accordingly, a minimum system capable

of resolving the most critical technology issues in space at the lowest possible cost was defined as Test Article-1 (TA-1). This would be followed in the testing program by TA-2, which would provide key cost data and information regarding how an SPS might be fabricated and assembled on orbit. In addition, further verification of two-dimensional phase control and thermostructural effects could be evaluated with TA-2. This effort would need to be completed in time to support programmatic decisions with respect to SPS by 1987. Finally, assuming a commitment is made, a partial prototype of the full SPS TA-3 will be fabricated.

A summary of the critical SPS test article functional requirements is listed in Table 3-1 along with the response of the various SPS objective elements to resolving the issues. The functional requirements are SPS technology advancement issues. This list was arrived at jointly by JSC, LeRC, MDAC, and Raytheon in a meeting at JSC. TA-1 operates in both LEO (TA-1L) and GEO (TA-1G) while TA-2 is used only in LEO. The TA-1L test activity is largely checkout and performance calibration prior to its being sent to GEO. TA-1 is used to resolve microwave issues, particularly for operation in the GEO environment and through the ionosphere (heated up-beam HF). TA-2 is involved primarily with the solar collector issues and system end-to-end functional verification.

A sketch of the TA-1 antenna is presented in Figure 3-1, which also indicates the length of the various waveguide sections and installation of the antenna and its phase control electronics. The horizontal arm of the antenna has a 2.39m length of waveguide at its center, while the vertical arm has two 2.39m sections, one on the either side of the center. The antenna is two waveguides wide, with one operating and the other for redundancy; the 46 amplitrons include 100% redundancy. The outboard waveguides (14.36 and 28.72m) use corporate feed with the amplitron in the center of the waveguide; all other waveguides are end fed.

Even though the length of the waveguides being powered by a single amplitron varies from 2.39 to 28.72m for amplitude tapering purposes, a separate phase shifter is employed every 2.39m to properly facilitate phase steering.

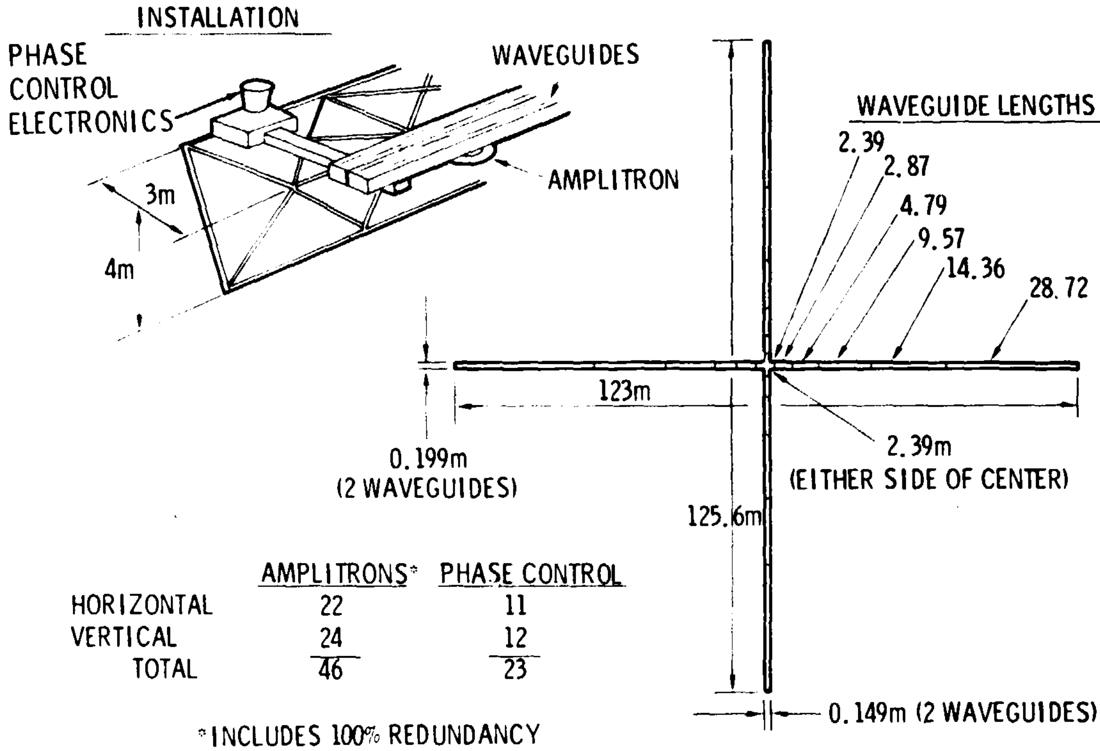
The antenna draws 75-80 kWe from the SCB power system during the intermittent periods it is under full-power. During these test periods, power will

Table 3-1

SPS OBJECTIVE ELEMENT/REQUIREMENTS MATRIX

Functional Requirements	Objective Elements		
	LEO		GEO
	TA-1L	TA-2	TA-1G
Evaluate Space Fabrication of Large Structures			
Solar Collector		X	
Microwave Antenna	X	X	X
Structural Interfaces	P	X	P
Evaluate Large-Scale Energy Collection and Distribution			
20K Volts	P	X	
Switching		X	
Evaluate Large-Scale Microwave Transmission and Control			
Ionospheric Degradation of Phase Control System			X
Thermostructural Effects on Phase Control System	X	X	X
Evaluate RFI Effects			
Direct Transmission from Amplitrons	X	X	X
Switching and Rotary Joint Sources	X	X	P
Voltage Level Regulation	P	X	P
Ionosphere Induced			X
Space Plasma Effects			
Arcing and Leakage	X	X	X
Spacecraft Charge Phenomena			X
End-To-End Functional Verification			
Thermal/Structural Interaction	P	X	
Phase Control System	X	X	
Power Transfer/Rotary Joint Current Density	P	X	
Prototype Manufacturing/Assembly Processes	P	X	

P = Partial Satisfaction



	AMPLITRONS*	PHASE CONTROL
HORIZONTAL	22	11
VERTICAL	24	12
TOTAL	46	23

*INCLUDES 100% REDUNDANCY

Figure 3-1. SPS TA-1 Antenna

be drawn directly from the SCB solar array during sunlight periods to minimize demands on the SCB power system. Additional details of TA-1 are included in Volume 3 of this report.

A sketch of the two beam-mapping satellites (BMS) used to test TA-1 and TA-2 are shown in Figure 3-2.

The TA-1 beam-mapping test procedure with the BMS-QC is illustrated in Figure 3-3. BMS-QC is in the same orbit as the SCB, at a range of 258 km for TA-1 and 3.4 km for TA-2. The solid line between the center of TA-1 and the BMS represents the geometric normal to the TA-1 antenna. Operation of the BMS pilot beam provides: (1) electronic beam steering toward the BMS, and (2) beam focus on the BMS, as depicted by the solid lines from ends of the antenna to the BMS. The first test procedure involves recording the pilot beam signals (phase angle) for each antenna subarray while steering and focusing. The recorded phase-angle signals will include, for example, compensation for TA-1 antenna distortion. The second procedure (pilot beam "off") involves the playback of the recorded signals to maintain the above focus and steering line-of-sight while rotating the TA-1 antenna through an angle $+\beta$. This rotation sweeps the beam past the BMS, where field strength is measured,

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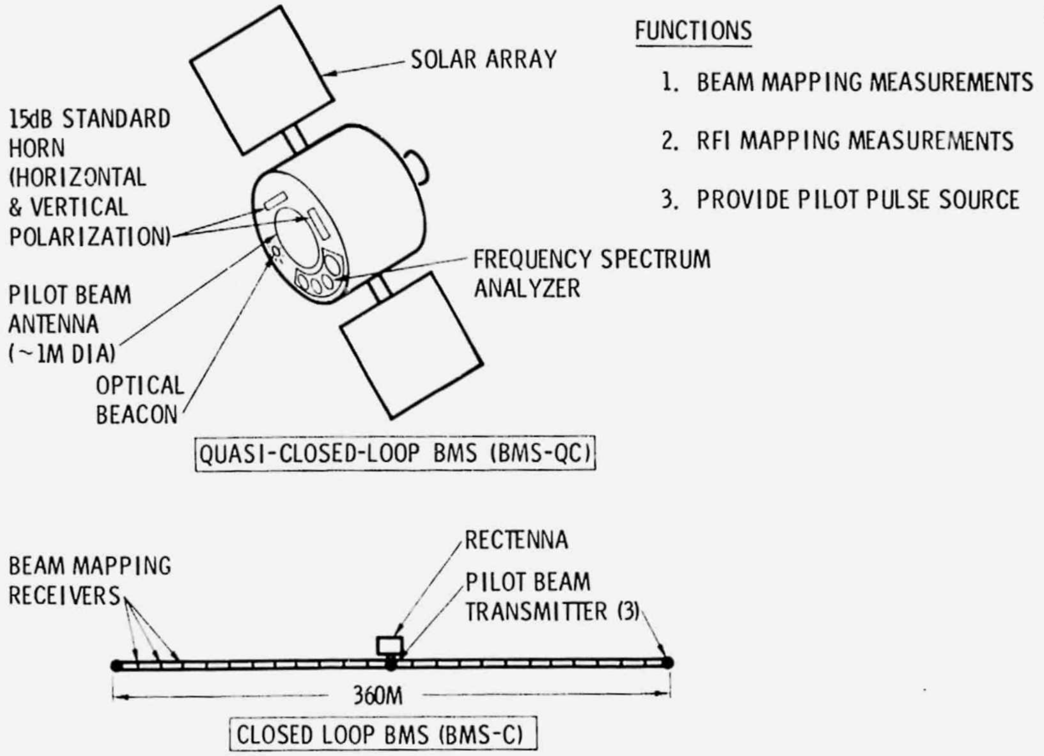

Figure 3-2. TA-1 and TA-2 Beam Mapping Satellites (BMS)

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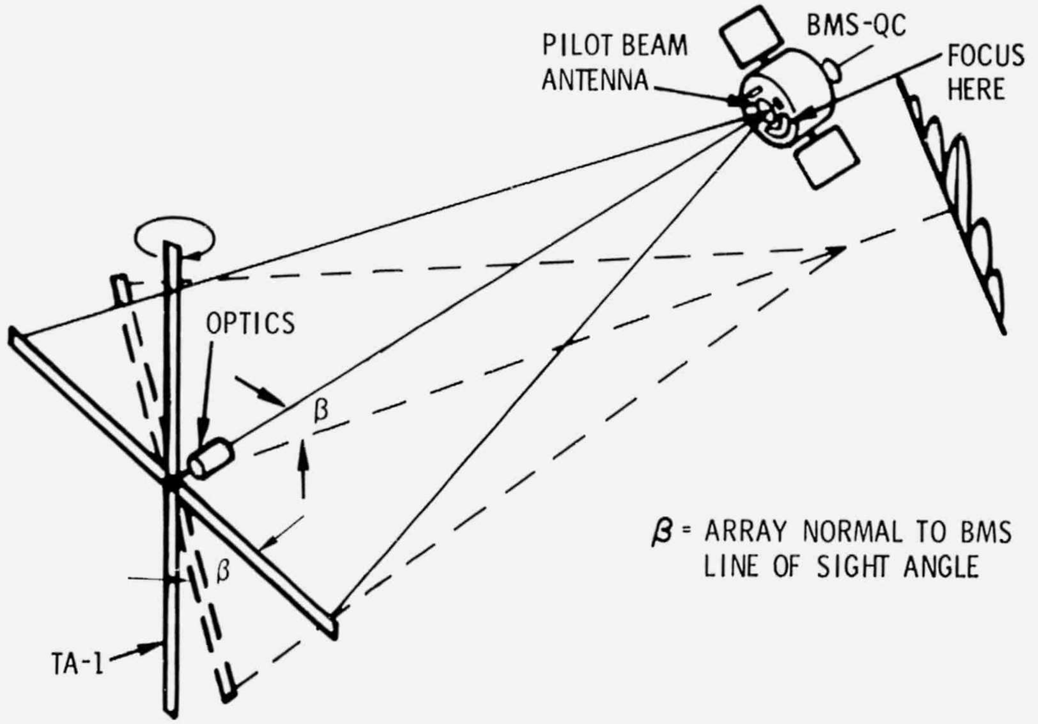

Figure 3-3. Beam Mapping Test Procedure

to produce data for a beam plot as illustrated by the example plot to the right of the dotted beam focus. This represents a "slice" through the beam for a given beam steering angle.

As the design of each objective element progressed, parallel operations analyses were performed to assure the producibility of the article in question. Also, parallel trade studies of ground versus on-orbit fabrication were performed as was determination of preferred fabrication and assembly techniques and equipment (reported later). Figure 3-4 illustrates the resultant construction techniques for TA-1 for (1) on-orbit fabrication on a permanently manned SCB, and (2) on-orbit assembly in a Shuttle-tended mode.

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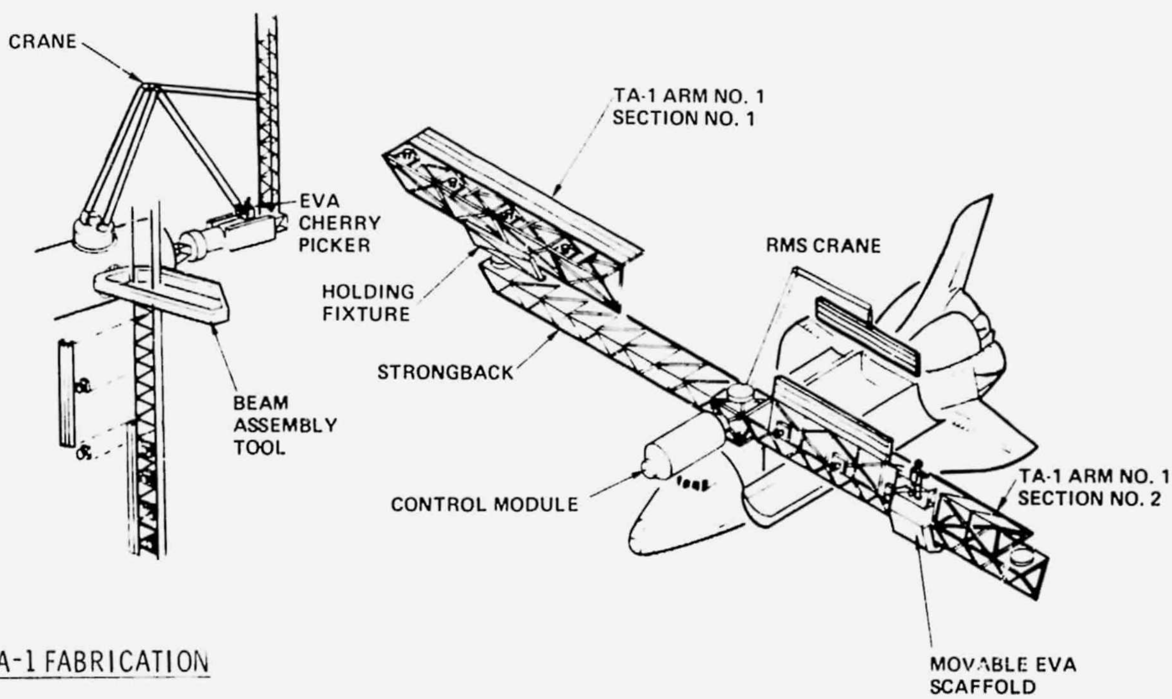

Figure 3-4. TA-1 Fabrication and Assembly

For on-orbit fabrication, the antenna consists of panels made up of waveguide/amplitron sections and phase-control electronics fabricated on the ground and attached to a support structure fabricated on orbit. The support structure, consisting of longerons and struts, is constructed from graphite polyimide tubes fabricated on orbit. The longerons are inserted into an assembly tool with automatic feeds. Support struts are put in place and attached by the use of standard industrial robots attached to the tool (the tool is delivered preassembled).

At periods in the construction process, support structure construction is stopped and the wire harness and power bus assembly and antenna panels attached by EVA, using a cherry picker platform attached to a crane. As each arm of TA-1 is finished, it is removed by the crane and transferred to the preassembled core (shown on the end of a ground-delivered power module) for final installation by EVA. The crane and cherry picker platform are discussed in Section 5.3 and Volume 3, Book 2, of this report.

For on-orbit assembly, the support structure for each arm is brought up in four sections, each approximately 15m long. Sections can be brought up completely assembled or partially collapsed. Each section is secured to a strongback assembly fixture, and the antenna waveguide and amplitron sections and phase control electronics installed by EVA using an appropriate scaffold which can be moved along the strongback. As the first section of an arm is completed, it is transferred to a holding fixture. Subsequent sections are joined until one arm is complete, at which time it is joined to a prefabricated core. The remaining three arms are built in the same manner.

Operational analysis of TA-1 construction was performed considering on-orbit fabrication in the permanently manned mode and on-orbit assembly in the Shuttle-tended mode. In the latter case, consideration was given to both delivering completely preassembled antenna support structure and having sections brought up partially collapsed and deployed on orbit.

For the on-orbit fabrication case, approximately 24 major steps, 19 of which are repeated for each arm, are involved in construction. Each step was examined, and time in terms of work shifts was prepared. It was interesting to note that the most time-consuming tasks were installation, checkout, and certification of the tooling. One of the slow jobs is the initial construction

of proof parts and adjustment of the robot operations. Actual fabrication of the beams is relatively rapid because it is all automated. Activities involving EVA, primarily installing antenna panels and electronics, are also time-consuming. The resultant assembly time is 80 shifts.

For the on-orbit assembly concepts, almost 40 steps are required in the assembly of a single arm. This fact, coupled with the use of scaffolding which must be moved after each installation on any arm section, results in significantly longer times to construct TA-1, between 155 and 159 shifts. See Volume 3, Book 2 for timelines and operational flows associated with TA-1 assembly.

The TA-2 configuration is presented in Figure 3-5 along with the key functional requirements and characteristics. The antenna is a 15 subarray (3 x 5) cluster constructed of subarrays approximately 3m square, the exact dimensions are presented in Figure 3-6. Fifteen subarrays is considered the minimum number required to adequately demonstrate the two-dimensional phase control in such a planar array. The center subarray operates at approximately the maximum power density of the prototype SPS (20 kW/m^2); the surrounding 14 subarrays operate at approximately an order of magnitude lower power density, again simulating the prototype SPS. This arrangement provides a two-dimensional thermal structural test, and the resulting antenna power is 479 kW_{RF} for the amplitron final configuration. The solar array dimension of 30m is the extreme width dimension; the active portion of the solar array is 20m wide. The 17m depth is from the top of the reflector to the bottom of the 10m beam cross braces. The reflector structure and the cross braces are both the 10m beams that serve as caps in the JSC SPS prototype concept.

A summary of the key SCB performance requirements to support SPS test article construction and test operations is presented in Table 3-2. Table 3-3 gives functional requirements. The crew size is the average crew size required for the tooling assembly and checkout, test article construction, and test and evaluation operations shown on the chart. The number of shifts required, at the average crew level indicated, are also shown for each of the test articles.

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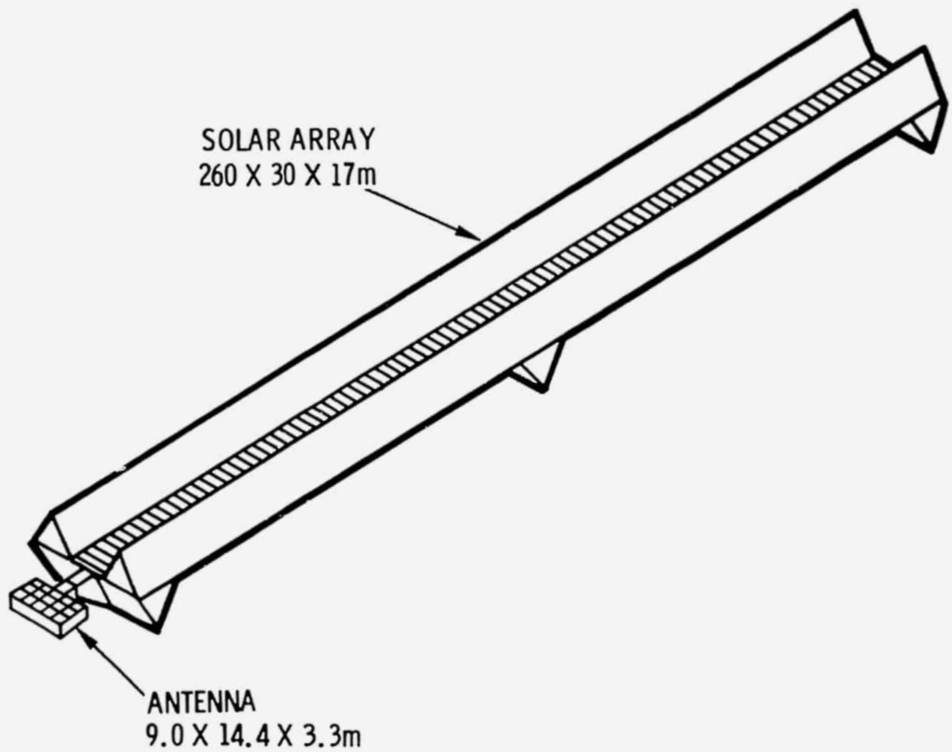

Figure 3-5. Test Article-2 (LEO)

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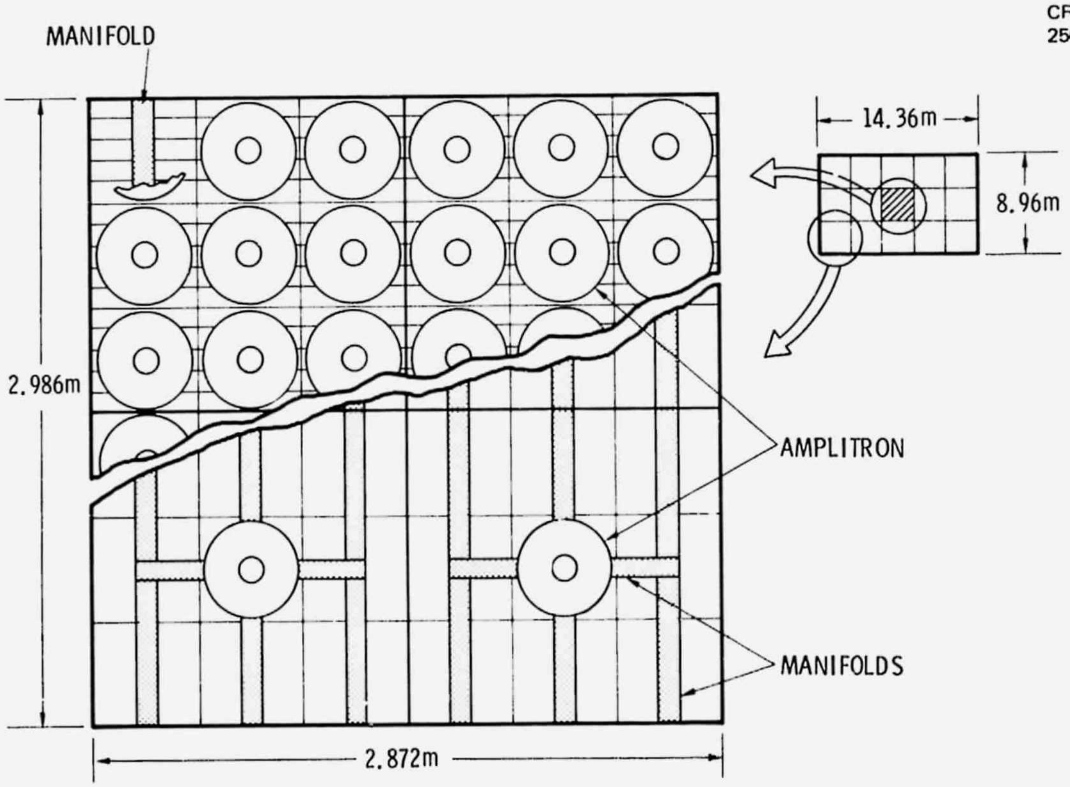

Figure 3-6. TA-2 Cluster Antenna

Table 3-2

SPS TEST ARTICLE

SCB KEY PERFORMANCE REQUIREMENTS

SCB Requirement	TA-1	TA-2
Crew Size (Avg)/Shifts		
Tooling	3/20	3/68
Construction	3/60	3/92
Test	1/970	2/730
Electrical Power (Avg/Peak), kWe		
Construction	6/10	9/12
Test	5/80 (at 20kV)	2/4
Construction Storage Volume, m^3	External-50	External-220
Orientation		
Construction	Antenna length to sun	Array to black space
Test	Antenna axis normal to velocity vector	Antenna axis normal to velocity vector

The average and peak electrical power requirements are shown for the construction and test phases. The TA-1 antenna tests require approximately 80 kWe at 20,000 Volts from the SCB power source. The storage volumes are for temporary storage, external to the SCB, of parts unloaded from the Shuttle during construction. These volumes are in addition to berthing and storage requirements for TA-1 and TA-2 tooling and fixtures, and temporary storage of 3-10m beams, 30m long (TA-2 cross braces).

The analysis of TA-1 and TA-2 construction revealed that significant EVA effort is required with a supporting crane. Of particular interest was the evaluation of what an EVA crewman needs to do his job. At each EVA work station, a significant complement of tools, services, restraints, force and torque reaction capability, etc., is needed. It is clear that the required

Table 3-3

SPS TEST ARTICLE
SCB KEY FUNCTIONAL REQUIREMENTS

Fabrication and Assembly Concept and Location — External/Assisted EVA

Crane Support Required for Construction and Maintenance

- Crane must be able to hold assembly for cut, trim and closeout

Semicontained Quarters Required at Each EVA Work Station

- Two EVA crewmen support
- Small parts/tool storage
- Crew restraints and aids
- Communications (voice and data entry)
- Surveillance TV
- Services (power pneumatics, fluids)

TV/Voice Surveillance of EVA crewmen

Alignment Check Required

- Test article-2 ' am
- Manufacturing mandrel

Two-Man EVA Airlock Required

Support Beam Fabrication Equipment and Assembly Tools

Construction Reject/Scrap Disposition

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capability is beyond that what can be conveniently carried by the EVA crewman as part of his "tool box". Separate, semicontained quarters at each EVA work station are needed (see Section 5.3).

Finally, fabrication operations require the space construction base to be capable of supporting automatic beam forming equipment, and as a companion requirement, supporting disposal of rejected parts.

3.2 EARTH SERVICE OJBECTIVE

The Earth Services Objective is to conduct research and development and construct large antennas and associated hardware required for:

A. Domestic and internation communications services

B. Earth and atmospheric survey

The design, tools, methods, and materials required to construct, assemble, and test large antennas in space which will maintain their structural integrity and beam-pointing capability during thermal and other stresses must be developed. Three antenna types for radiometry and communications will require development, i.e., dish, multibeam lens, and large-phased array antennas. (Reference: Study of the Commonality of Space Vehicle Applications to Future National Needs, Aerospace Presentation, September 1975).

To conduct passive microwave radiometry, Outlook for Space-SP-386 called for long-wave length microwave system development leading to operational systems with antennas up to 100 and 300m in diameter for conducting marine resource evaluation, all-weather crop prediction, and regional water balance forecasting.

As a precursor to the development of larger size antennas, a 30m antenna was selected as a prototype for the program with the intent to reduce development risk and the cost of changes or modifications incurred in the learning process of on-orbit large-scale construction. The 30m size was chosen for the following reasons:

- It is a minimum-size, full-spectrum radiometer requring on-orbit assembly.
- It is of minimum size, allowing simulation of all construction techniques required by larger systems.
- It achieves almost an order of magnitude increase in performance over planned systems.

For the communications case, a 27m multibeam lens (MBL) antenna was selected. The benefits provided by communications satellites are well-known. The large communications satellite objectives are simply an extension of existing capability to increase available services. They do represent a departure from present practices by placing equipment complexity and size in orbit rather than on the ground. As a result, use of the systems is made available to a much greater percentage of the population, i.e., antenna size, transmitter power, and receiver sensitivity are sharply reduced. The MBL, for instance, can serve 100,000 post offices, providing an "electronic mail" system.

Based upon the design requirements and trade studies, a design concept for the 30m radiometry satellite was evolved. Its characteristics are shown in Table 3-4. It is designed to cover all frequency bands of interest in earth observations while scanning perpendicular to the orbit track. Stabilization requirements were assumed at approximately 10% of the beamwidth. Since the satellite is passive in nature, power requirements should not exceed 2 kW.

Table 3-4
DESIGN REQUIREMENTS – RADIOMETRY SATELLITE

System		Antenna	
Frequency bands (GHz)	0.6-118	Diameter (m)	30
Radiometer channels	28	Beamwidths (deg)	2.3-0.012
Beam stabilization (deg)	±0.0015	Polarization	Horizontal and vertical
Altitude (km)	340-800	Scan angle (deg)	100
Inclination (deg)	54	Surface tolerance (cm)	0.03
Power required (kW)	2		

A parabolic antenna was analyzed for use as a scanner. An original scan-angle requirement of 100 deg was reduced to 15 deg in an attempt to halt the onset of an aberration called coma, which manifests itself as an unsymmetrical pattern shape with side lobes higher on the boresight side of the main beam The amount of coma introduced is a function of the feed displacement off-axis and the focal length-to-diameter of the system. For this reason, an f/D ratio of 0.75 was initially selected in lieu of the 0.25 to 0.5 commonly used for conventional ground antennas. However, for a gain loss no greater than 1 dB (Rayleigh criteria), the number of 0.16 deg beamwidths scanned was found to be limited to 13 on either side of the axis.

The f/D ratio was then increased to 2.25, resulting in the ability to scan 112 beamwidths. However, due to the physical dimensions of the horn, only 49 could be placed within the beam displacement length of 9m on each side of the axis (98 total). The null-to-null beamwidth/beam was found to produce insufficient overlap, resulting in an irregular amplitude beam pattern. An extremely awkward configuration with a focal length of 67.5m also resulted which, with minor expansion or contraction of the feed legs, could result in significant dish warping and pattern degradation. As a result, a parabolic torus was selected for concept development due to its scanning capability.

Large space antennas generally are either erectable or deployable. Antennas are placed in the erectable category if their shape is such as to make deployment difficult, i.e., unfurling mechanisms and hinges become complex, and damping must be employed to prevent excessive backlash. Another factor to be considered is the surface tolerances which can be achieved. Higher frequencies require tighter tolerances.

The 30m scanning parabolic torus, which is used for earth observations and limb sounding radiometry, is in the erectable category due to its odd shape and operation up to 118 GHz. The 9.1m ATS-6 antenna is in the deployable category. The symmetrical shape provided by the paraboloid of revolution allows a simple unfurling mechanism to be employed. The antenna type is

usually used to produce spot beams in TV broadcasts, high-rate communications, and planetary radiometry applications. Today's technology allows their operation to 10 GHz at 40m diameters and 0.5 GHz with 180m diameters.

Based upon the design requirements and trade studies, a design concept for the 30m radiometry satellite evolved. Its characteristics are shown in Figure 3-7. Although not visible in the illustration, feed horns are mounted on the periphery of the rotating wheel. Microwave radiation is reflected from the parabolic torus on to a secondary surface (ellipse) and then into the feed horns. The microwave signals are then input to radiometry receivers and their output processed.

It should be noted, that other sensors such as scatterometers, operating in other regions of the frequency spectrum are also expected to be carried within the body of the satellite. However, the concentration in this study is focused on the assembly of the large antenna structure required by the longer wavelengths.

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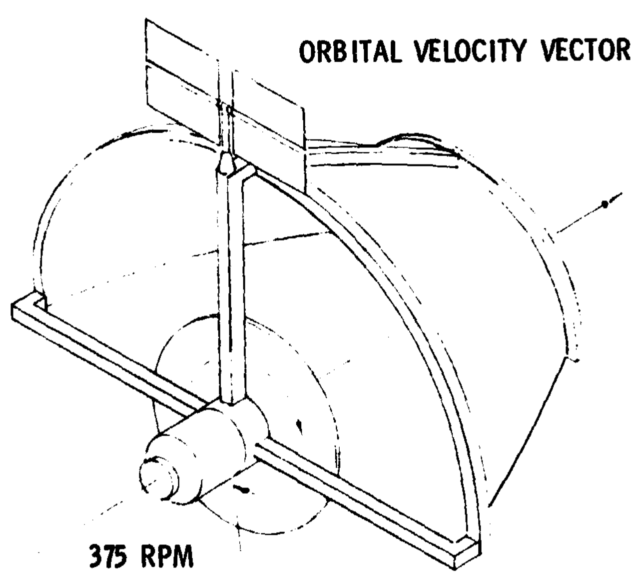
CHARACTERISTICS	
WEIGHT (KG)	15,400
BUS POWER (KW)	2.0
PANEL POWER (KW)	4.8
SOLAR PANEL AREA (m^2)	45.5
BATTERY CAPACITY (AHR)	140
HUB DIAMETER (m)	4.3
HUB LENGTH (m)	6.2
STABILITY (DEG)	± 0.00015
SWATH WIDTH (KM)	1.16



MECHANICALLY SCANNED RADIOMETER

Figure 3-7. 30M Radiometry Satellite

An analysis was made to determine what problems might ensue in scaling the 4m Shuttle imaging microwave system design's mechanical scan to 30, 100, and 300m antenna sizes. A 340-km altitude and a frequency of 53 GH_z were chosen as a design point since the latter represented the highest frequency at which a contiguous swath width was required. This, in turn, established the rotation rate of the scanning wheel at approximately 400 rpm for the 4m design.

The focal length of a spherical antenna is half the radius and values for each antenna size were found. With the arm length and rotation rate of 400 rpm established, the resultant "g" level at wheel edge was found. It was found that the level is questionable at 30m and unacceptable at 100 and 300m diameters. In addition, either wheel rotation rates or the number of feeds at each given frequency would actually have to be increased to maintain continuous swath widths as the wheel size increases.

Due to the complexity engendered in attempting to scale up the 30m antenna to larger diameters, while retaining the surface tolerance and scan rate requirements of the higher frequencies, it was decided to split spectral band assignments. As shown in Figure 3-8, divisions were made where the diameters required to provide 1-km resolution at 800-km altitude were just exceeded. The result is to leave three frequencies of interest for the 100-300m antennas and reduce surface tolerance RMS requirements to 0.48 cm. Since scan rates to produce contiguous scans at the highest frequency of of interest are now also reduced, mechanical scanning via a wheel is again an attractive technique. A detailed trade between it and electrical scanning is required before making a selection.

An electronic mailing system in concept would have a 1,000-beam multiple-beam antenna system in space whose beams could be pointed to 100,000 post offices in the United States. Each post office would have a 0.91m diameter antenna on the roof aimed at the space antenna and would need data-processing equipment. The post office would be able to send mail to any other post office by a processor requesting transmission routes through the space system. For sizing the system, each 21.6 x 27.94 cm page would have 10^5 elements (0.0254 by 0.0254 cm). Each post office would send 10 pages per second. Assuming a data compression capability of 10:1, each post office would

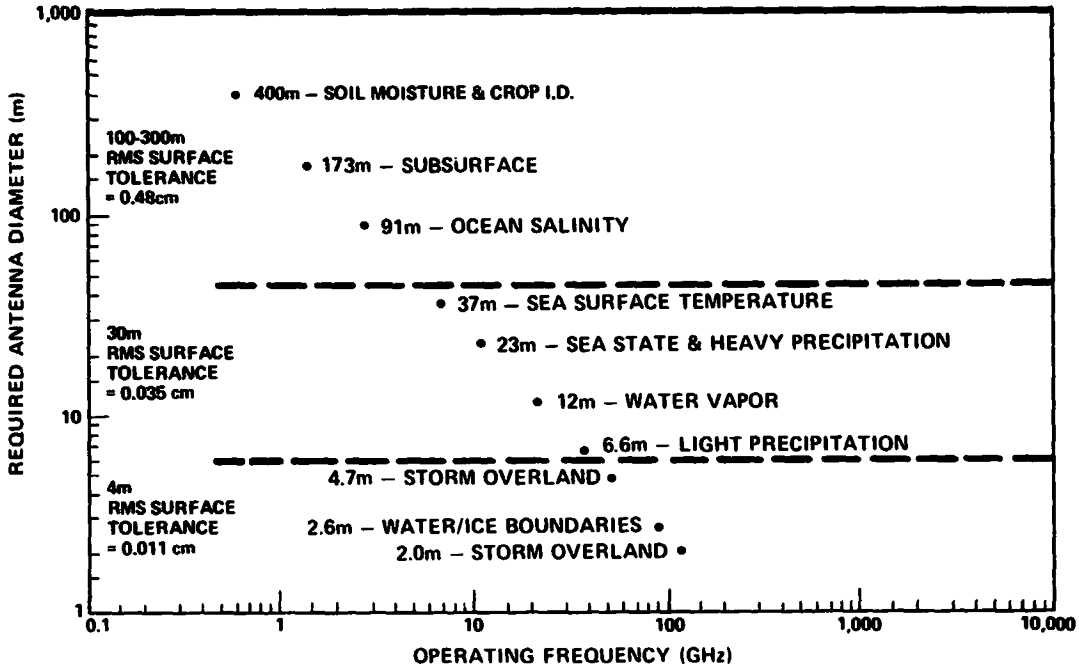


Figure 3-8. Allocation of Spectral Bands to Antennas (Source: A Forecast of Space Technology 1980-2000, Table 3-2, NASA SP-387)

transmit 1 mbps of data. For 100,000 post offices, this would be 10^5 mbps passing through the space antenna at one time.

The design requirements shown in Table 3-5 were developed to provide this capability. A frequency band of 8 GHz (rather than a lower band) was selected due to spectrum congestion and to reduce the antenna size requirements. Bandwidth, and number of beams stem directly from this concept. Frequency reuse is specified due to the shortage of available frequencies. Power requirements are derived based upon a link margin analysis together with the gain-temperature ratio and effective isotropic radiated power (EIRP) level.

The DC power requirement represents the summation of all individual transmitter receiver requirements plus a power allocation for other satellite subsystems. Antenna requirements are, in general, derived (beamwidth, spacing, diameter) to meet assumptions on post office location. Beam-to-beam isolation and sidelobe levels are requirements placed on the antenna to prevent interbeam interference.

Table 3-5

DESIGN REQUIREMENTS – MULTIBEAM LENS COMMUNICATIONS SATELLITE

System	Antenna
Frequency: X-band (8 GHz)	Beamwidth: 0.09 deg (half power)
Bandwidth: 2 x 1,000 MHz (Rx and Tx)	Beam spacing: 0.1 deg on centers
Number of beams: 1,000	Antenna type: lens
Frequency reuse: 100 times	Diameter: 27m
RF power: 5 to 10 watts/beam	Beam-to-beam isolations: 25 dB
Stabilization:	Sidelobes: <30 dB
±0.01 deg azimuth and elevation	Gain (each beam): 60 dB
±0.02 deg in rotation	Number of feedhorns: 1,000
Switch control: at baseband	Polarization: linear (adjustable)
1,000x1,000 ports, 10 dB loss	
<1 μsec switch time>	
>30 dB isolation	
G/T: +30 dB/°K	
EIRP: +94.7 dBW	
DC power required: 16,750 kW	

Design characteristics of the communications satellite that meet the requirements previously defined are illustrated in Figure 3-9. These characteristics in turn, allow the definition of the number of Shuttle launches required to place the satellite components in orbit and help to establish the requirements for the on-orbit assembly timelines. With the exception of the satellite weight, which is quite heavy due to its graphite and epoxy construction, the characteristics are conventional and may be met with state-of-the-art components.

The on-orbit assembly of the 30m radiometer and the 27m MBL was analyzed. Time lines and operational flows can be found in Volume 3, Book 2.

CHARACTERISTICS	
WEIGHT (KG)	29K
BUSS POWER (KW)	16.7K
PANEL POWER (KW)	19.6K
SOLAR PANEL AREA (m^2)	186
STABILITY (DEG)	± 0.005
MODULE DIAMETER (m)	3.66
MODULE LENGTH (m)	4
LENS THICKNESS (m)	0.061

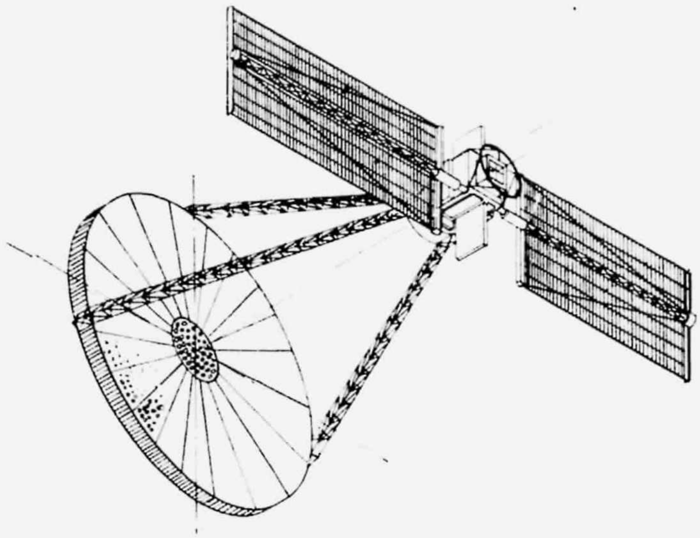


Figure 3-9. 27M Multibeam Lens Satellite

The key performance requirements with regard to impact on the space construction base configuration are listed in Table 3-6. A crew of three, a crane operator and two EVA astronauts, are required during the construction phase. Checkout will require two crewmen, as will test, with one crewman operating a console controlling a remote satellite and the other collecting data on the satellite's operation. Average power requirements are estimated at 2 kW primarily for operating the crane or rotating work platform and illuminating the work area. The pressurized volume shown will house electronic test equipment, alignment aids, satellite/equipment, and self-powered assembly tools. The unpressurized volume is required for holding the radiometer satellite components prior to their assembly.

The key functional requirements for SCB support of antenna assembly are listed in Table 3-7. It is seen that much the same types of functional support required for earth-based construction will be needed on orbit. However, many additional functions must be provided to support EVA operations. Included in this latter category are the work stations with restraints and tethers, mobility devices, and surveillance functions.

Table 3-6

KEY ANTENNA PERFORMANCE REQUIREMENTS

	30M Radiometer	27M MBL
Crew Total		
Assembly	3 - 71.5 shifts	3 - 54 shifts
Test	2	2
Power (avg)		
Assembly	2kW	2kW
Test	2kW	2kW
Volume		
Pressurized	$60m^3$	$60m^3$
Unpressurized	$392m^3$	$901m^3$
Satellite/Signal Source		
Mass	500kg	500kg
Frequencies	0.6 - 118 GHz	8 GHz

Table 3-7

KEY ANTENNA FUNCTIONAL REQUIREMENTS

Crane Support

- Parts translation
- Positioning aid (power assist)

Quarters at Each Work Station

- Two EVA crewmen support
- Small parts/tool storage
- Crew restraints and aids
- Communications (voice and data entry)
- Surveillance TV
- Services (power pneumatics, fluids)

360° Work Rotation (Single-Plane)

TV/Voice Surveillance of EVA Crewmen

Precision Alignment Tools

Umbilical/RF Link to Spacecraft

- Checkout
- Solar array deployment
- Fluid/gas fill, vent, and drain

Two-Man EVA Airlock

3.3 SPACE PROCESSING OBJECTIVE

The Space Processing Objective is to conduct reasearch and development to determine the technical and economic feasibility of commercial inorganic processing and biological materials applications, and support, as appropriate, the initial commercial utilization of these processes.

Preliminary studies and experimental results from the Apollo, Skylab, and ASTP missions indicate that space processing may be justified as a commercial source of improved or unique products very useful on earth. Market projections for these new products such as silicon ribbon, ultrapure glasses, pharmaceuticals, and biological materials (e.g., the ensyme urokinase) are very significant.

It is projected that space processing will ultimately be justified if it can become a commercial source such materials not obtainable at competitive costs on earth. In this context, this objective has a strictly commercial emphasis, i.e., made-in-space products having a unique utility in the economy. Therefore, the characteristics of the program to transition from R&D to full-scale commercial production in space must reflect the following:

- Continue applied R&D activities in basic chemistry and physics, materials sciences, pharmaceuticals, electronic materials applications, optical materials and components, and other man-made products that offer a commercially significant potential.

- Develop in-space processes and procedures that ensure control of material characteristics, uniformity, dimensional precision, and on-schedule production of quantities commensurate with industrial operations.

- Demonstrate production yields in sufficient quantities and quality to assure commercial interest and economy as opposed merely to demonstrating scientific or technical feasibility.

- Demonstrate man-machine interactive designs that will take cost-effective advantage of automated, semiautomated, and manual operations, including all aspects of the production process (i.e., fabrication, assembly, test, quality control, packing, and transportation).

Three cases were selected representative of a broad class of future commercial space processing activities. The first was the production of the enzyme urokinase, which centered around a separation procedure and two cell growth cycles. This process involves the production of a biomaterial in final form in space and offers significant improvement in product potency than possible on earth. The second case selected described the production of an ultrapure glass in space representative of high technology, unique materials useful in new and novel products of the future. The third case was production of semiconductor grade silicon in ribbon form. This product could supply to a very large future demand at significant reduction in cost.

For each of the three cases studied, a typical research plan and development schedule was prepared (Figure 3-10). This plan depicts the time-phased steps necessary to carry the prototype product from basic research through process development and optimization to the ultimate goal of commercial production. As shown, there is an evolution through five classes of activities leading to production: (1) ground based research, (2) sounding rocket flights, (3) STS/sortie flights including early Spacelab missions, (4) STS/Spacelab flights, and (5) SCB flights. Each class of activity follows a progression of more complex operations involving larger complements of equipment, longer mission durations, and extended capabilities in space.

The schedule shown in Figure 3-10 is the development plan for the bioprocessing case structured around the production of the enzyme urokinase. The plan starts with groundwork which is currently being pursued in the laboratory to provide insight into separation methods that would be candidates for space flight and the advantages gained by the microgravity environment. The plan evolves to pilot-plant operation and full-scale commercial production of the product (urokinase in highly purified and potent form) by the 1990-91 time period. Similar plans were constructed for the other two cases.

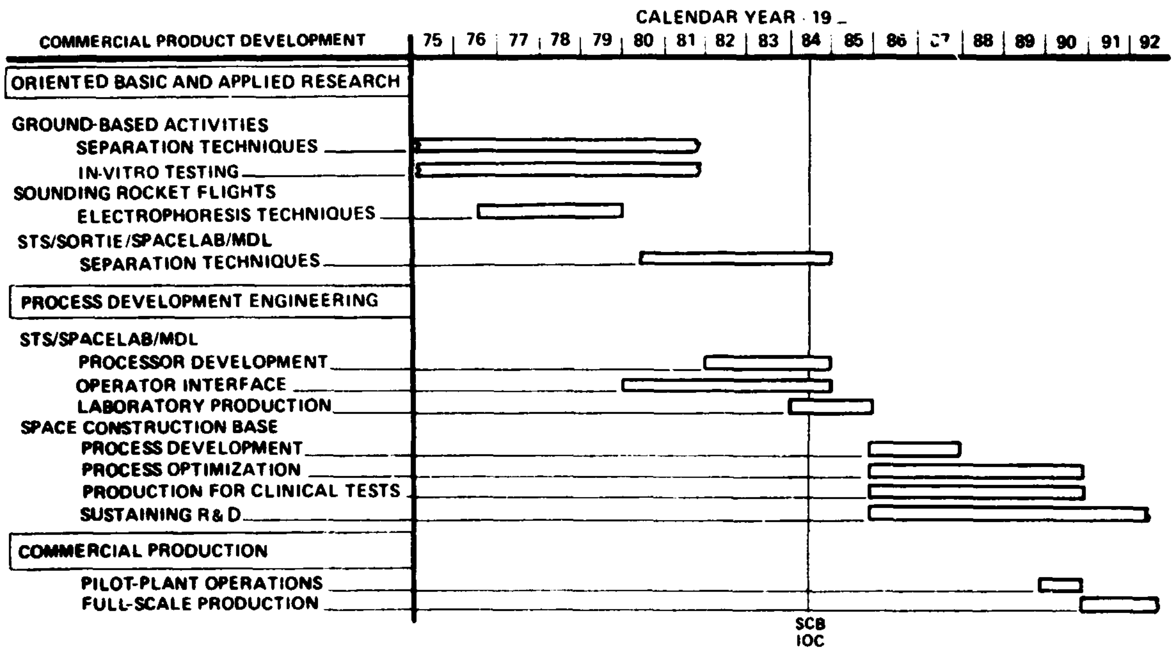


Figure 3-10. Development Schedule – Bioprocessing Case

The important observation that is drawn from this plan is that the step associated with optimizing a process and reducing it to commercial practice involves years and requires a Space Station for support.

For the bioprocessing case examined, one possibility for the mechanization of the process is shown in Figure 3-11. This flow is typical (insofar as the scope of activities and equipment) of the processing steps required for many biological materials prepared from living cells. A key step in this process is the separation of urokinase-producing cells from other cells by continuous electrophoresis in a microgravity environment. The other steps involving growth of a producing colony of cells and an enzyme production period are also shown on the figure. The typical time span for the steps shown is 52 days. During a mission period of 90 days, two overlapping 52-day cycles could be accommodated.

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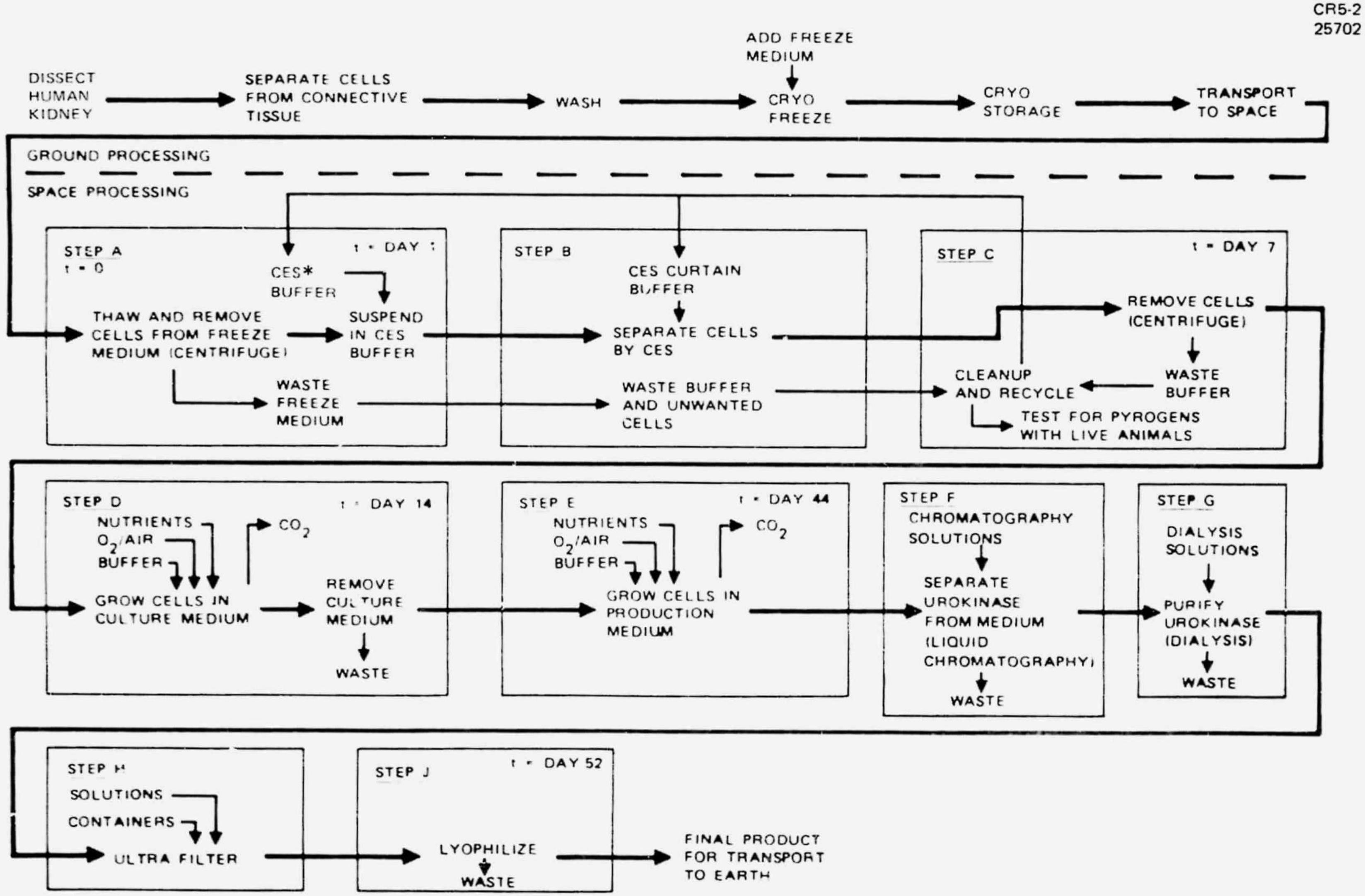

* CES = CONTINUOUS ELECTROPHORESIS SYSTEM

Figure 3-11. Urokinase Process

The urokinase process is typical of the production of an enzyme from living cells. According to researcher Dr. Grant Barlow of Abbott Laboratories, this type of process, by isolating the enzyme from other materials offers to increase product potency significantly. He bases this estimate in part on the successful Electrophoresis Technology Experiment on Apollo-Soyuz. The encouraging results of this experiment showed that one fraction of the cells separated produced six times more urokinase per cell than ground-based control. He predicts additional improvements in all steps of the procedure (i. e. the separation process and the two growth steps) to yield an overall improvement up to 600 times what could be expected on earth. This vast improvement by space processing would provide the impetus to commercialize the product in order to satisfy future public demand. Ground production without this improvement may not be capable of satisfying the demand; this is an important feature of the case.

As seen in Figure 3-11, the urokinase production process involves the exacting control of nine basic steps. At each step there are many parameters (e.g., process time, temperature, pressure, flow rate, pH gradient, electrical potential, local chemistry) which must be held within certain defined and restrictive ranges. Determination and refinement of the set points which provide the maximal and optimal yields will be a most demanding exercise.

Figure 3-12 highlights nine examples where an intellectual resource (man) would be a most desirable, if not mandatory, attribute. Even though many portions of the process and control thereof would be automated, the requirement remains that the process be under the influence and overall control of highly trained specialists, as reflected by current production methods employed on earth for the research and production of biological materials.

The equipment needed for the bioprocessing case is shown in Table 3-8 with the schedule for producing urokinase, assuming a 90-day mission is shown in Figure 3-13.

The minimum time required to complete the nine process steps under a given set of assumptions is about 42 days. This requirement is predicated on a 30-day production cycle, a value near the maximum useful life of the

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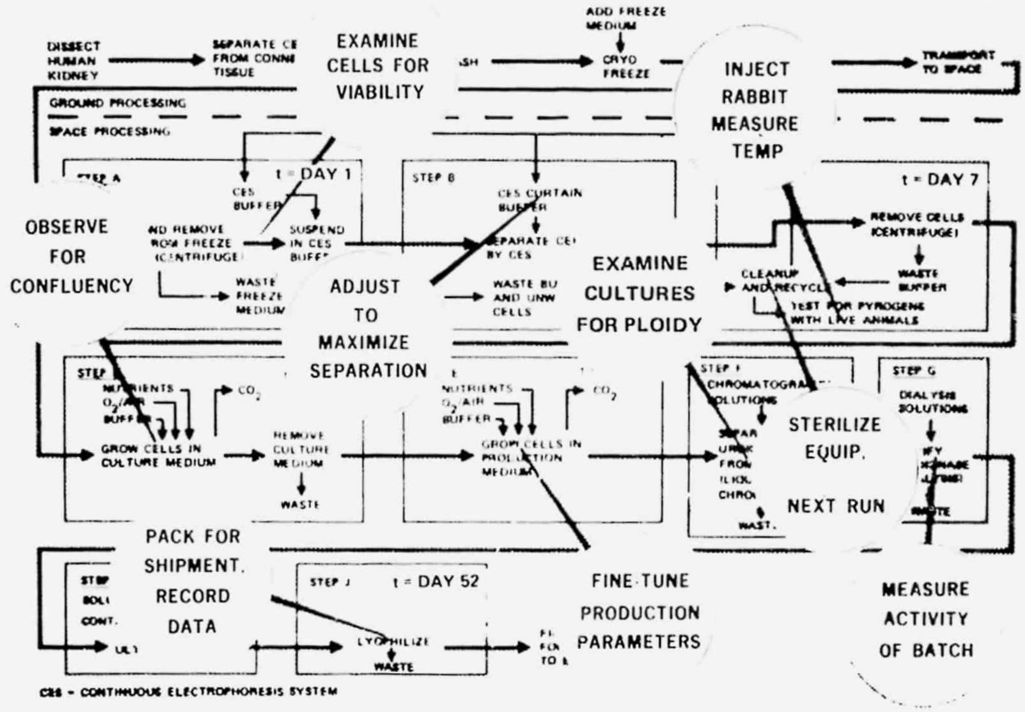

Figure 3-12. Role of Man in Urokinase Process Development and Optimization

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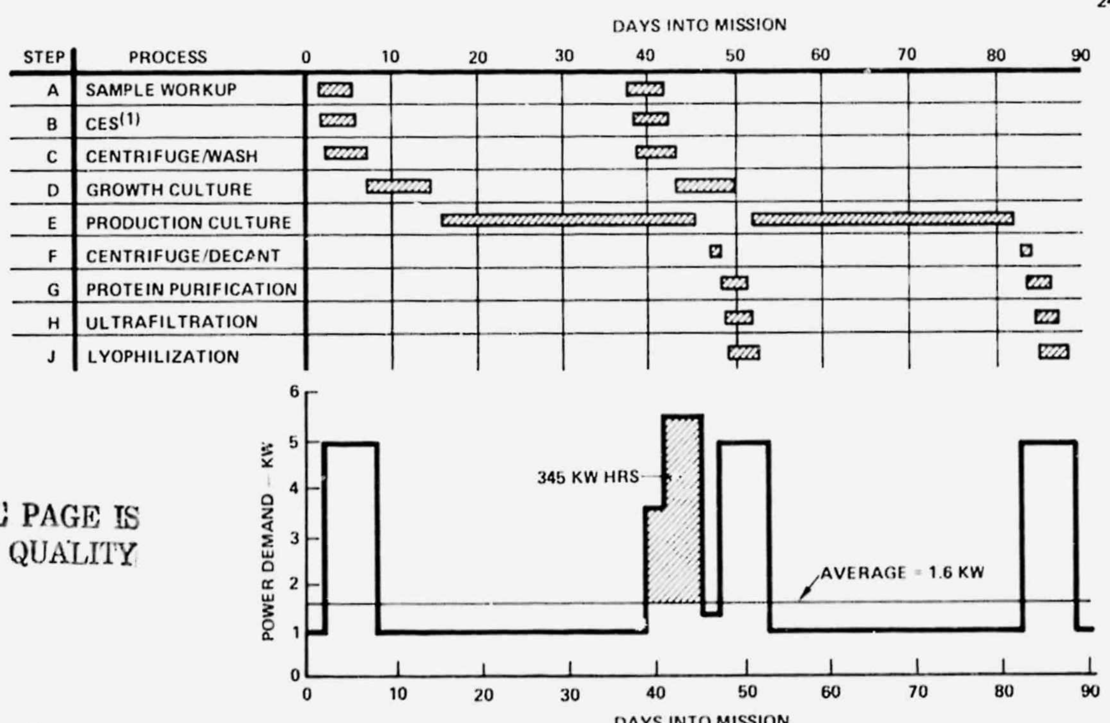

(1) CES = CONTINUOUS ELECTROPHORESIS SYSTEM
1 KG UROKINASE PRODUCED IN SPACE = 10,000 TREATMENT REGIMENS

Figure 3-13. Processing Schedule Case Example (1 kg Urokinase Produced During Mission)

Table 3-8

BIOPROCESSING EQUIPMENT

Item	Weight (kg)	Volume (m^3)	Peak Power (W)
Continuous Electrophoresis System (CES)			
Cooling system mechanical	100		
Cooling reservoir fluid	20		
Cell and hydraulics including pumps	100		
Buffer reservoir and flow control	25		
Power supplies	15		
Collection system, filled	12		
Subtotal	272	0.44	2,500
Buffer reconditioner	45	0.04	100
Centrifuge, refrigerated	275	0.65	2,000
Growth/production culture chamber, gas exchange, controls	115	0.45	500
Protein purification (solvents, buffer, tanks, pumps)	150	0.70	200
Ultrafiltration system	15	0.15	200
Lyophilizer, using mechanical pumps and refrigeration	400	0.70	3,500
Low-temperature refrigerator	70	0.12	350
Total	1,342	3.25	5,350*
			(1,600 avg.)

*Peak power, at time of simultaneous operation of CES, centrifuge, culture system, and refrigerator

production culture. It is also limited by an assumed 12-day allocation for delays in startup of the first cycle, gaps between process steps in any single cycle, and the time between the end of the last unit operation in the mission and the end of the mission period itself. This is a reasonable estimate representing combined operator time for production startup, termination, and delays between unit operations for handling, material transfer, etc.

The time periods for the other seven process steps (i.e., continuous electrophoresis separation, centrifuge/wash, growth culture, centrifuge/decant, protein purification, ultrafiltration, and lyophilization) are functions of the number of processors used, the volume of material produced, and the time allowed for the growth culture. During a 90-day mission, two complete and overlapping production cycles of 52 days duration would produce about 1 kg of urokinase.

Figure 3-14 depicts the yield growth as a function of mission duration. It will be noted that a mission period of 180 days allows a ten-fold increase in production over the 90-day mission. A year-long mission could produce sufficient product to meet the total demand of 600,000 treatments.

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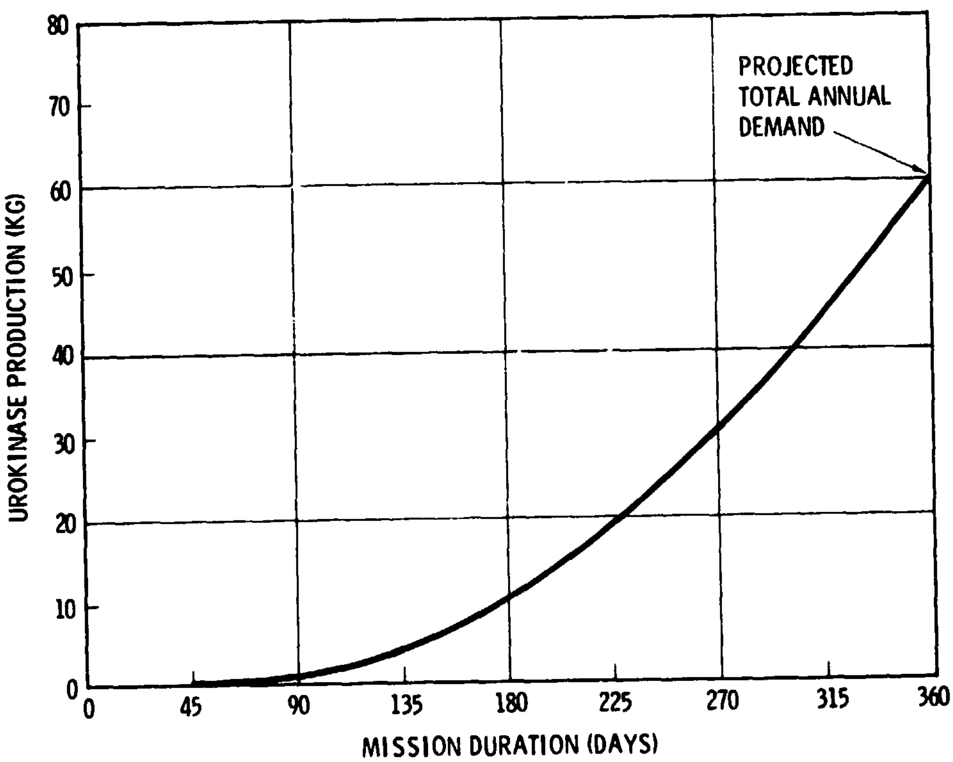

Figure 3-14. Bioprocessing Yield Growth

The process steps as outlined above represent only one technically feasible approach. There may be ways to improve and optimize specific parameters associated with the process. For example, two sequential cycles using one CES unit were suggested. Another approach would be to perform a single culturing of the production cells using several CES units, followed by serial cycles of production, purification, and lyophilization of the urokinase. This modification, as well as others, offers the potential to enhance the specific production per unit weight of the processing setup. Such optimization activities are typical of the factors to consider in the early (1984-86) time period.

In addition to the apparatus involved in the actual process development, process optimization, and pilot production of the urokinase, other facilities would be required for an analysis and product-testing capability and crew washup, garment sterilization, and waste material control. Depending upon the design approach finally selected for the process, the entire work area in the immediate vicinity of the equipment might be required to be maintained at 4°C to protect the heat-sensitive proteins. Some degree of biological isolation will be also required to protect the process from other environmental areas of the station and vice versa. These requirements have been summarized in preliminary form as shown in Table 3-9.

Tables 3-10 and 3-11 present in summary form the requirements for the ultrapure glass and shape crystal processing cases.

Table 3-9

REQUIREMENTS SUMMARY – BIOPROCESSING CASE

Primary Processing Equipment

- Continuous electrophoresis system (3 required)
- Refrigerated centrifuge
- Dialysis, ultrafiltration, and lyophilization units
- Culture and growth incubators
- Mass properties: 2,110 kg, 5.3 m^3
- Electrical power: 4.[illegible] kW avg, 13.7 kW peak

Support Equipment and Supplies

- Analytic Services: microscopic study, wet chemistry, mass determination
- Animal holding and observation station
- Work fluids and recycle apparatus
- Analytic fluids, containers, washdown solutions, wipes, and liners

Environmental Conditions and Constraints

- Bioisolation, contamination control, microbial monitoring, flammables
- Bioprocessing compartment: 4°C ambient
- Microgravity: $< 10^{-3}$ g
- Materials stored at cryogenic temperatures (-70°C)

Operational Considerations and Work Force

- Crew size = 3; round-the-clock coverage during critical periods
- Total access to processing equipment for adjustments and changeout
- Mission duration of 90 days or longer
- Allowance for growth in equipment, supplies, and working volume
- Proprietary data

Table 3-10

REQUIREMENTS SUMMARY – ULTRAPURE GLASSES CASE

Primary Processing Equipment

- Two contactless furnaces for melting and shaping
- Two furnaces for annealing and cladding
- Atmosphere and process control systems
- Mass properties: 1725 kg, 4 m^3
- Electrical power: 17 kW_{avg}, 26 kW_{peak}

Support Equipment and Supplies

- Inspection and glass characterization station
- Manipulators and glass handling apparatus
- Material storage, packaging, and containers
- Gases, vacuum access, and operating supplies

Environmental Conditions and Constraints

- Potential hazards: high-temperature, toxic, and corrosive materials
- High thermal rejection (26 kW_T)
- Protection of crew during hazardous operation
- Microgravity: $<10^{-3}$g

Operational Considerations and Work Force

- Crew size = 4, round-the-clock coverage during critical periods
- Total access to furnace equipment for adjustments
- Back-of-the-rack access for maintenance and servicing
- Allowance for growth and equipment changeout
- Proprietary data

Table 3-11

REQUIREMENTS SUMMARY – SHAPED-CRYSTAL CASE

Primary Processing Equipment	
	Shaped-crystal processor
	General-purpose furnace
	Solar-cell processor
	Mass properties: 7200 kg, $52 m^3$
	Electrical power: $9.7 kW_{avg}$, $16.5 kW_{peak}$
Support Equipment and Supplies	
	Crystal characterization equipment
	General-purpose shop equipment
	Control and data system
	Gases, supplies, and containers
Environmental Conditions and Constraints	
	Potential hazards: high-temperature, toxic, and corrosive materials
	Vacuum port to 10^{-7} torr
	Protection of crew
	Microgravity: $<10^{-3} g$
Operational Considerations and Work Force	
	Crew size = 3; one shift operations
	Total access to ribbon and solar cell processors
	Back-of-the-rack access for maintenance and servicing
	Allowance for growth and equipment changeout
	Proprietary data

3.4 SUPPORTING OBJECTIVES

In Part 1 of the study, a number of objectives were investigated that resulted in the definition of mission hardware which is general in nature because each element is intended to support a relatively broad spectrum of activities. These supporting objectives from Part 1 are:

- <u>Space Cosmological Research and Development – To perform R&D on Space Cosmology related components and construct a large microwave telescope.</u>

- Multidiscipline Science Laboratory – Provide a multidiscipline laboratory to conduct space research in the basic disciplines.
- Sensor Development Facility – Provide a facility for the test and evaluation of optical sensors for earth sciences and cosmological phenomenon.
- Living and Working in Space – Demonstrate long-term living and working in space as related to other manned space objectives.
- Orbital Depot – Perform the necessary R&D and develop the orbital operations for an orbital transfer vehicle system.

The study approach taken in Part 2 was to assess the capability of the mission hardware derived in Part 1 to support "test cases". Where discrepancies occurred, appropriate requirements were modified.

As an example, a Mars Sample Return Mission (see Volume 3, Book 2) in which the SCB acts as a "way station" for analyzing materials and gases returned from Mars to assure that there are no properties which would be harmful to terrestrial life. As a result, physical capabilities and functions which must be provided by the Multidiscipline Laboratory were identified (e.g., a personnel decontamination station and discretionary volume for test chambers).

The requirement for precursor R&D work in Space Processing revealed the need for six bays of equipment shown in Figure 3-15, which are typical of a space processing/materials science mission hardware complement of a multidiscipline laboratory. The basic and applied research that could be accomplished with this laboratory would be capable of supporting a long-term program from which new products with commercial interest could emerge.

The laboratory could support research eventually leading to applications such as biological products, optical products, electronic products, and structural materials. The investigative thrust of the research would follow the development of scientific understanding of and insight into phenomena involved in materials processing in general. Space-based studies of topics such as solidification, heat conduction in liquids and gases, phase transformations, the shape of the liquid-gas interface as controlled by surface-tension-motivated

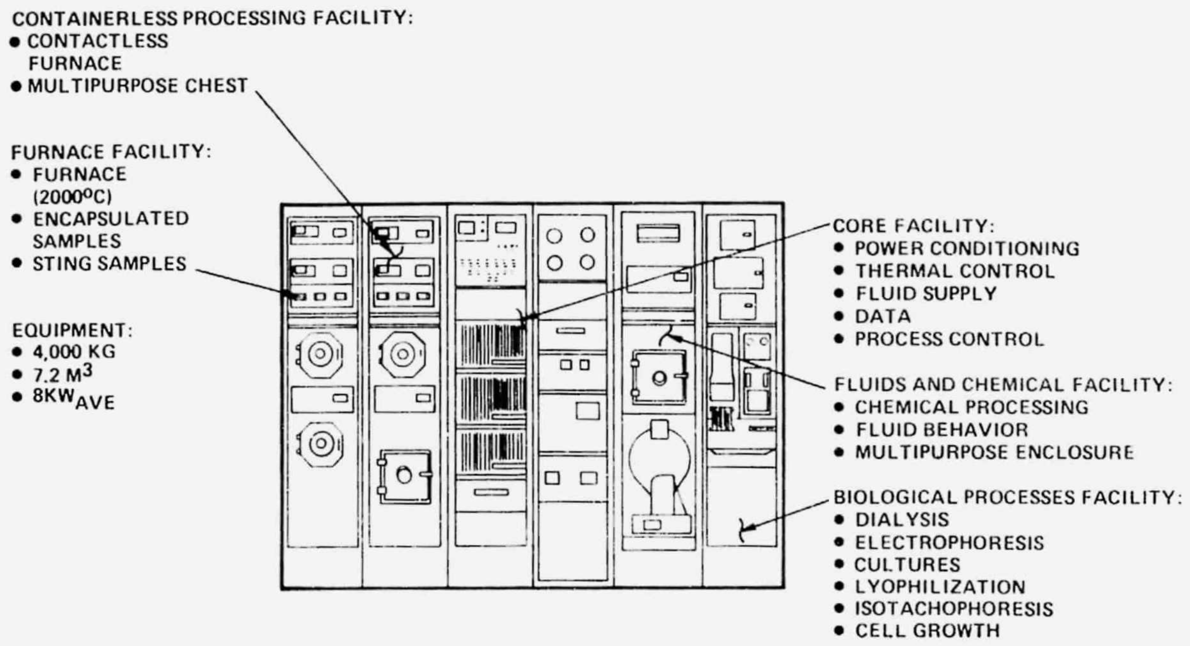

Figure 3-15. Space Processing Equipment Required for Multidiscipline Laboratory

flow, the dynamics of flames and combustion processes, the kinetics of vaporization and condensation, the dynamics of froths, and diffusion in fluids in a temperature gradient are merely a sampling[1] of the use of such a facility.

The orbital depot objective was investigate in considerable depth. An early trade study revealed that providing the depot function from the Shuttle rather than as an integral part of the SCB was an attractive option. Therefore, this mode of operation was studied, and compatible orbital transfer vehicle designs and operations were developed as summarized in Volume 3, Book 2.

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[1] Suggested by Dr. R. A. Oriani, United States Steel Corp.

Section 4

FABRICATION AND ASSEMBLY REQUIREMENTS AND APPROACHES

4.1 SPACE FABRICATION AND ASSEMBLY REQUIREMENTS

Space fabrication of components, as opposed to transporting finished parts to orbit, can be justified if total construction costs are reduced. In general, three conditions must be met to satisfy this requirement. First, density of the component in question must be so low that transportation costs may be significantly reduced by shipping only bulk materials to orbit. Secondly, the fabrication process "orbital overhead" costs must be less than the transportation cost saving. This second condition typically involves automation of the process to reduce required fabrication manhours. Hence, sufficient production to amortize the necessary investment in fabrication equipment is also a strong requirement. Examples of automated fabrication processes that may be simply automated are pultrusion (plastics and composites) and roll forming (ductile metals). Such machines are currently highly developed and capable of producing a great variety of cross sections (tubular, channels, Z-sections, etc).

While the cost of an orbital construction worker is high (on the order of $\$10^4$ per hour), the cost of developing fully automated assembly equipment is also great and, similar to the orbital fabrication problem, can only be justified when production will be sufficient to amortize the tooling. Remote manual assembly has limitations due to crane or manipulator dynamics and geometry. Thus EVA is utilized primarily to extend the crane's capability and hence reduce assembly time.

TA-2 was selected as being representative of the types of requirements that would be imposed on orbital fabrication and assembly. For the purpose, of the study it was assumed that the economic advantages of SCB support of space construction of TA-2 would be significant. The MDAC concept for TA-2

employs prototypical beams with a 10m side section as shown in Figure 4-1. These beams would be assembled to form a 260m long solar collector with a 5200 m^2 active area. The 10m beam would be applicable to the prototype full-scale SPS.

4.2 CONSTRUCTION APPROACH

An earlier MDAC concept for production of the full-scale SPS prototype 10m truss beam is illustrated in Figure 4-2. Roll forming machines are utilized to continuously produce the three triangular beam caps from rolls of aluminum sheet strips. Each cap is formed from two strips and fastened together, for instance, by projection welding. A centrally located roll forming machine continuously produces discrete lengths of tubular truss members. Upon completion the truss members are picked up by programmed robot arms and attached to the triangular cap flanges by the fastener tools. Beam alignment is maintained by control of individual roll forming machines. The prototype 10m beam making module is 13m in diameter, and hence well beyond the capacity of the current Orbiter.

Automated SPS construction as typified by the approach described above is founded on two currently well-developed technologies: (1) continuous roll forming of linear structural members from raw stock and (2) automated assembly with programmable robots. Figure 4-3 illustrates the Yoder roll forming machine commonly used in aerospace manufacturing. As adapted to the fabrication of 10m triangular beam caps, fewer (though considerably longer) rolls of material would be required for the relatively simple forming task.

Figure 4-4 illustrates a typical industrial robot. It is interesting that advanced versions of these machines can be automatically programmed by manually moving the "hand" through the intended motion pattern thereby commanding the robot to follow the prescribed series of movements.

4.3 TA-2 FABRICATION AND ASSEMBLY METHOD

The fixture design for TA-2 fabrication and assembly is based upon an advancement of the prototype construction system previously illustrated. This concept continuously produces a completely finished solar collector in a fully automated

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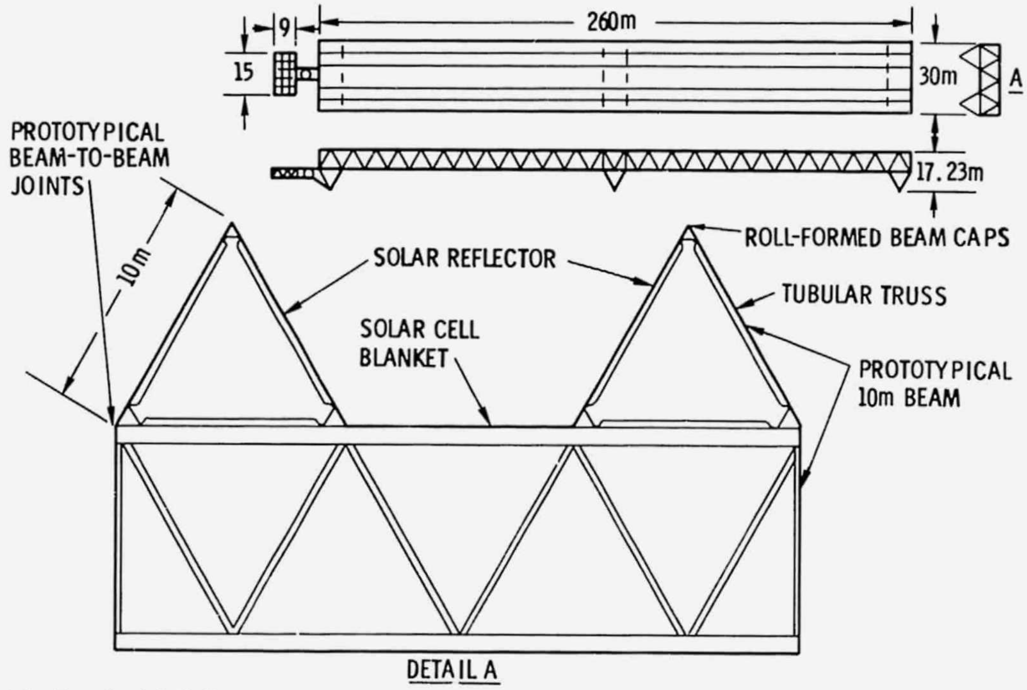

Figure 4-1. Test Article-2 Concept

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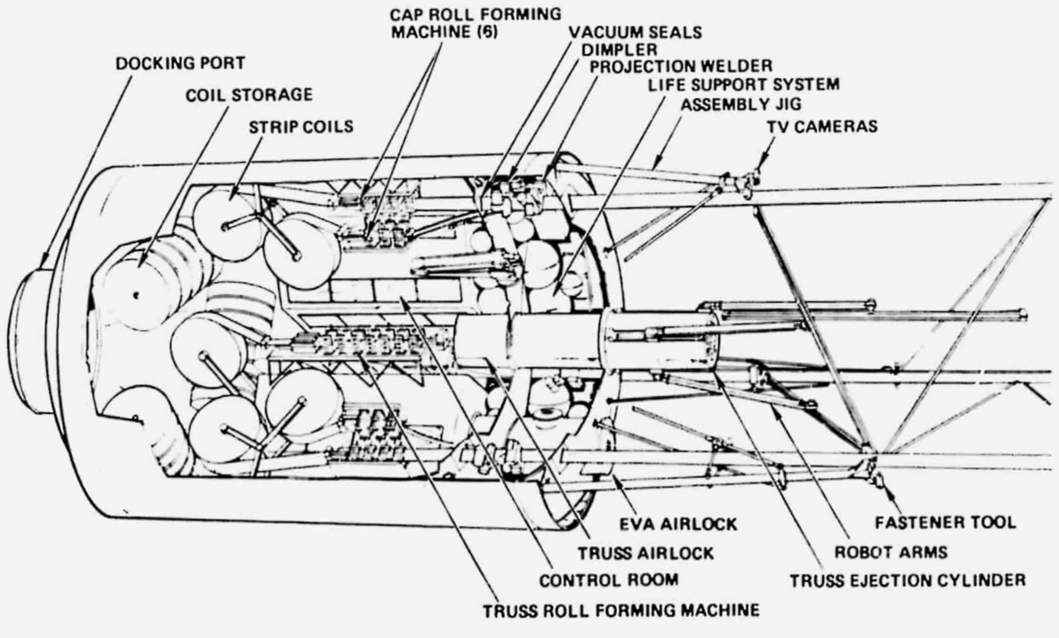

Figure 4-2. Production Prototype 10-Meter Truss Fabrication and Assembly Module

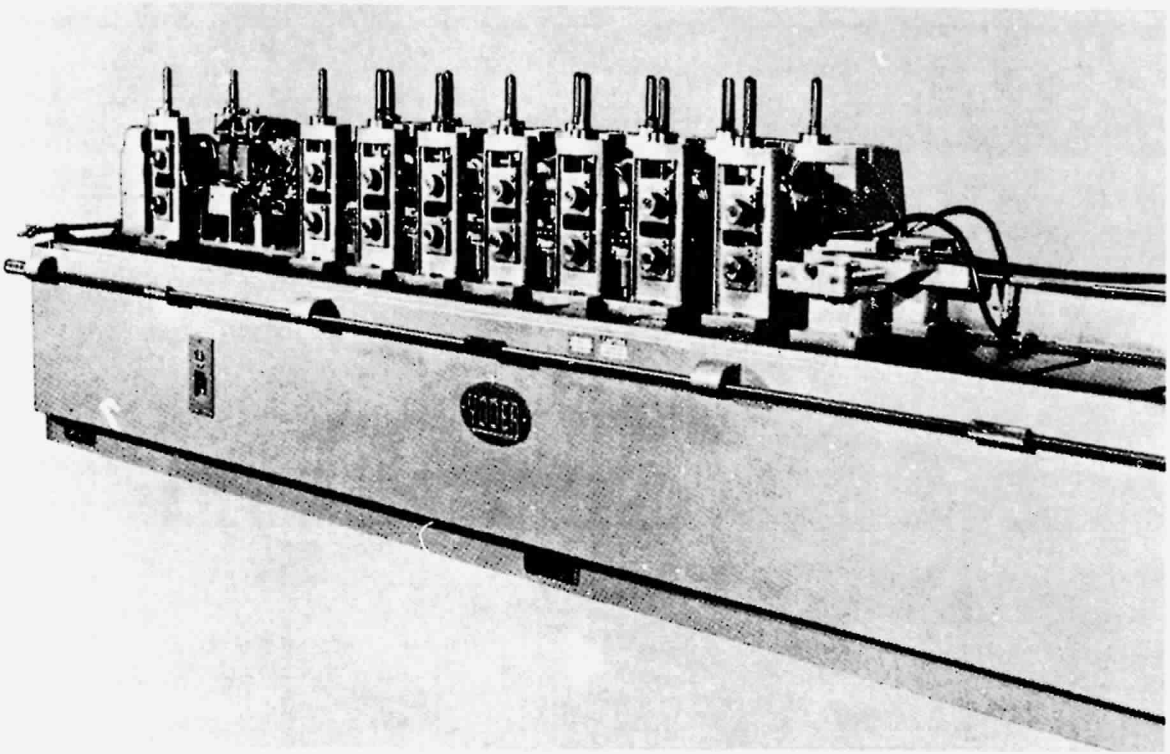

Figure 4-3. Industrial Roll Forming Machine

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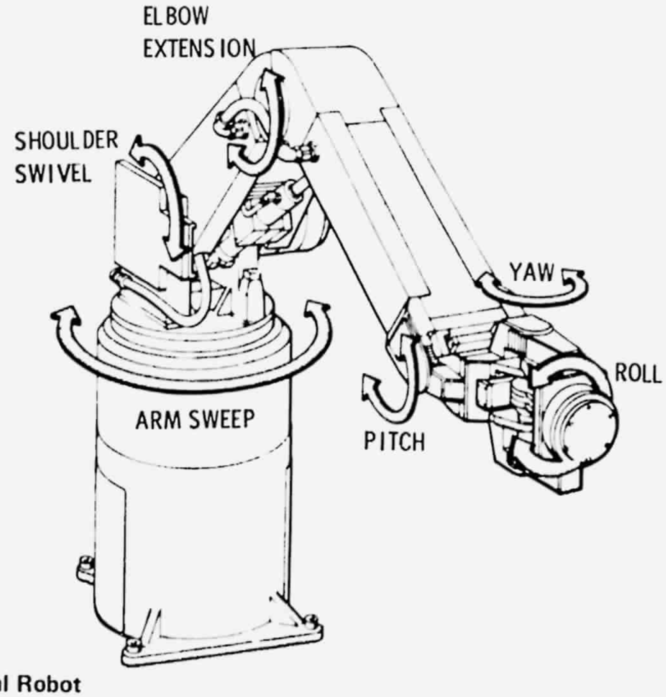

Figure 4-4. Typical Industrial Robot

assembly line as shown in Figure 4-5. Roll forming machines and associated fastening machines for the 10m beam caps are located in unpressurized, thermal control shrouds. Six of these are mounted on a jig frame to simultaneously produce the required longeron caps. Two robots, mounted on the jig's main beam, pick up prefabricated truss tubes from a spring-fed magazine and clip them to the emerging beam caps. As the truss/cap junction passes through a truss attach head, a structural bond is formed (projection weld, large-diameter hollow rivet, or one of several other viable options). Pretensioned reflector and solar cell blanket materials are continuously deployed from rolls mounted between the jig frame arch and main beam, and on the main beam respectively. Reinforced edges of reflector sheets are attached to the beam cap flanges by staples or blind rivets. However, the avier solar cell blanket material would induce extreme stresses into the beam caps during light/dark thermal cycling if it were rigidly attached. Blanket edges are therefore suspended from the beam caps by constant-force springs. While several options exist, it appears that blanket-to-electrical power bus connections are only required at extreme ends of the collector.

Prior to beginning fabrication of the longerons, the fabrication and assembly fixture is used to produce three 30m lengths of 10m beam. These are stored under the construction module and used as needed for structural cross members in the collector. Attachment of these large members to the emerging longerons would utilize the mobile crane and EVA.

Electrical power required by the fixture is a linear function of cap development rate and estimated at approximately 1-kw/m/min (exclusive of lighting requirements). Since deployment of the full Test Article-2 solar array in one week implies an average rate of only 0.026 m/min, average power consumption is quite low.

Figure 4-6 shows a three-view of the TA-2 automated solar collector construction fixture previously described. Note that a berthing port fitting on the main beam allows the fixture to be attached to the construction base.

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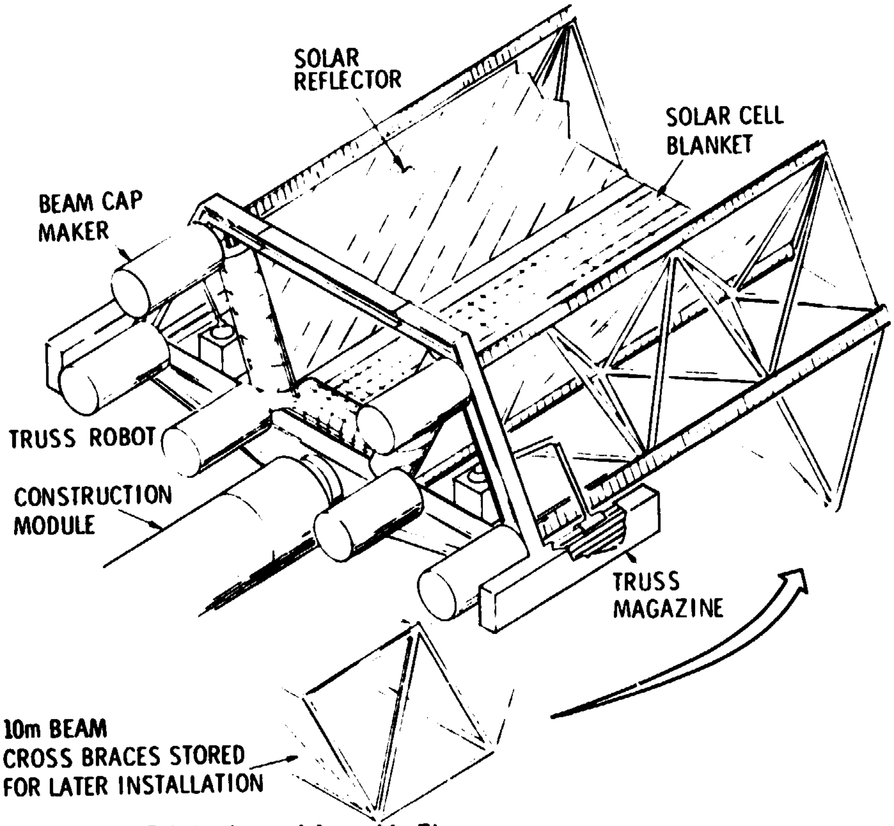

Figure 4-5. Test Article-2 Fabrication and Assembly Fixture

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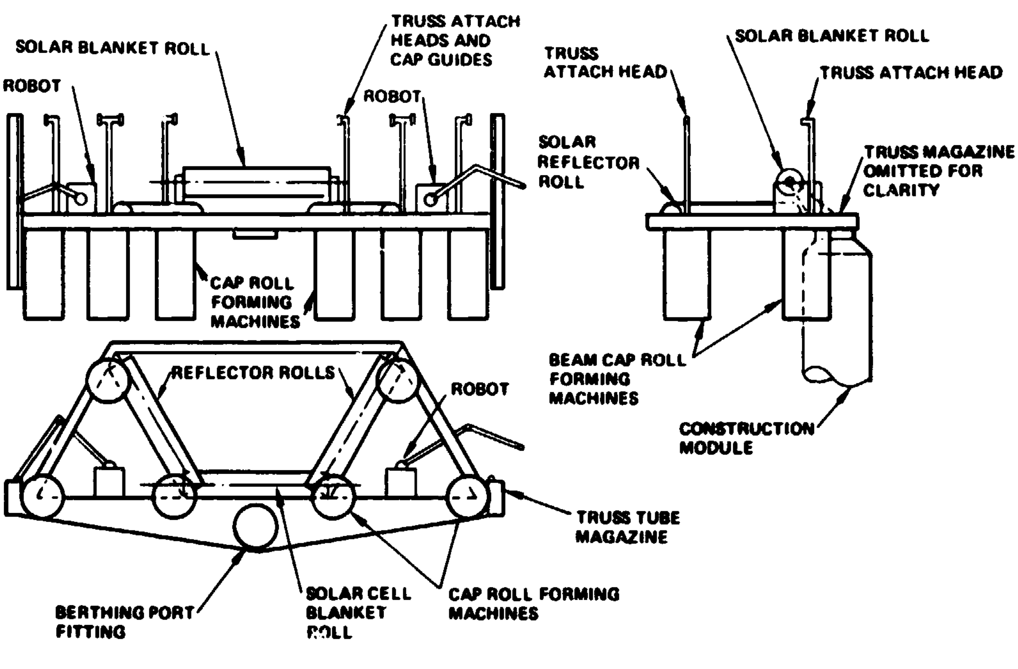

Figure 4-6. Test Article-2 Automated Solar Collector Fabrication and Assembly Jig

The roll forming unit consists of two sets of rollers: one set of six rollers per the upper cap of the beam, a second set for to lower cap. The longer set of six rollers forms the apex of the triangular 10m beam cap, the cap being 1m on the side. Sheet aluminum stock used to form the cap is stored in coils. A lower closure cap is formed by the set of three smaller rolls. As illustrated in Figure 4-7, each roll progressively forms the sheet stock. All are driven by an electric motor and geared together for synchronization. While it may be possible to reduce the number of rolls, an increasing number results in low roll pressures and reduces the vacuum lubrication problems.

Not shown, but included in the roll forming module, is a spot welding machine to attach upper and lower cap segments to each other.

The solar collector fabrication and assembly jig is itself totally ground fabricated, and its design allows assembly and checkout prior to launch. Components are then shipped to orbit on two pallets, which are berthed to the construction support module while the jig is assembled. Actual assembly is by EVA-assisted crane as in the sequence illustrated in Figure 4-8.

4.4 SOLAR ARRAY AND ANTENNA CONSTRUCTION APPROACH

Construction of the solar array for TA-2 is predicated on automatic beam forming. The fabrication and assembly sequence is shown in Figure 4-9. A construction tool is brought up, assembled (by EVA and crane), and aligned. Automatic beam cap forming equipment is then brought up and installed at each apex of the triangular beam areas on the tool. Industrial robots are strategically located to position ground fabricated support struts. The beam cap forming machines roll form the caps which are extended out simultaneously. At the appropriate time, a strut is loosely attached by spring clips at the appropriate point by the industrial robot and a spot welding mechanism energized to fix it in place. Three 30m long beams are fabricated in this manner and then temporarily stored. Fabrication of the solar array support structure is then initiated. A little over 10m of structure is fabricated. A 30m cross beam is put in place by the crane and attached by EVA. Solar cell blankets and reflector rolls are installed on the tool and unrolled and attached to the

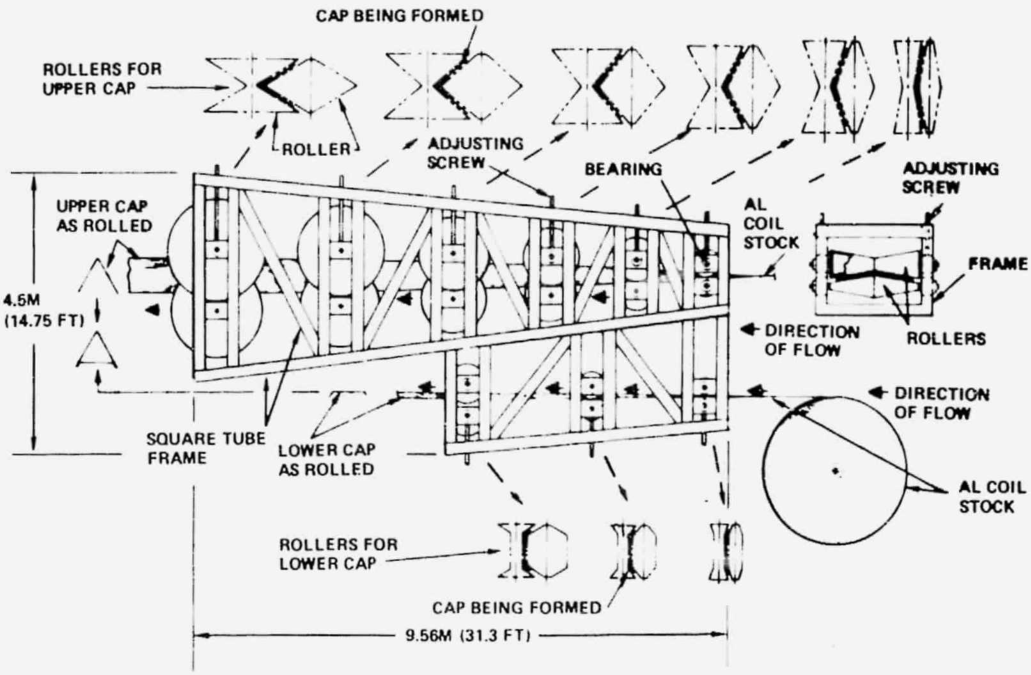

Figure 4-7. Metal Roll Forming Unit

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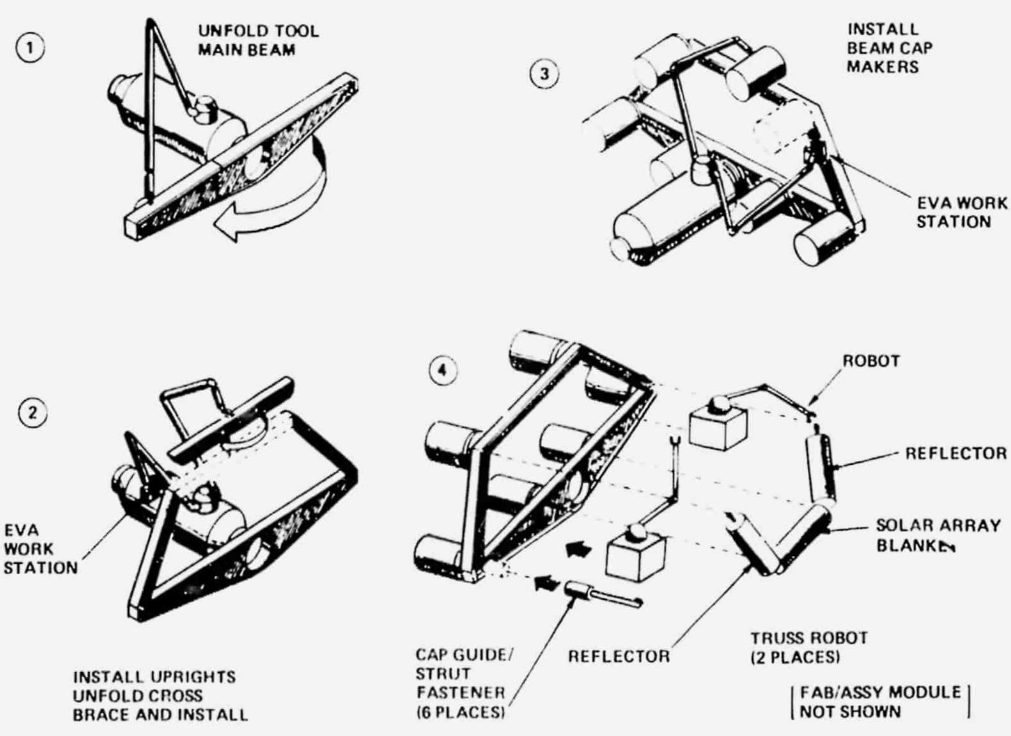

Figure 4-8. Test Article-2 Solar Collector Fabrication and Assembly

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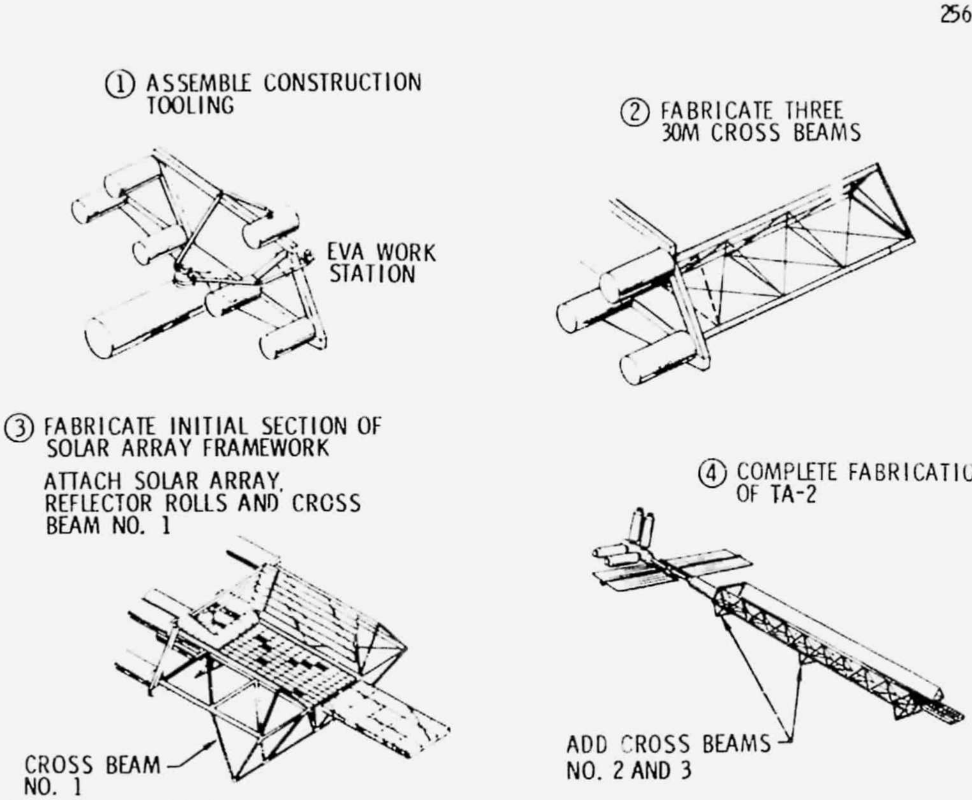

Figure 4-9. Test Article-2 Solar Array Construction

support structure by EVA and crane. The antenna is then brought around and attached at the end of the solar array structure; 125m of beam is then fabricated; and the second cross beam installed. The full 260m is then fabricated and the last cross beam installed. System tests can then commence.

The automated antenna truss assembly fixture for TA-2 shown in Figure 4-10 consists of seven tube feeds positioned on a jig frame so that the antenna longerons can be simultaneously deployed. Strut attach fittings are thermally bonded to the longerons by a device immediately downstream of each tube feed. Three programmed robots, mounted on the jig frame between the upper four longerons, place the tubular struts against these fittings where they are attached by thermal bonding or hollow rivets. This entire fixture may be transported as a fully assembled entity within the cargo bay.

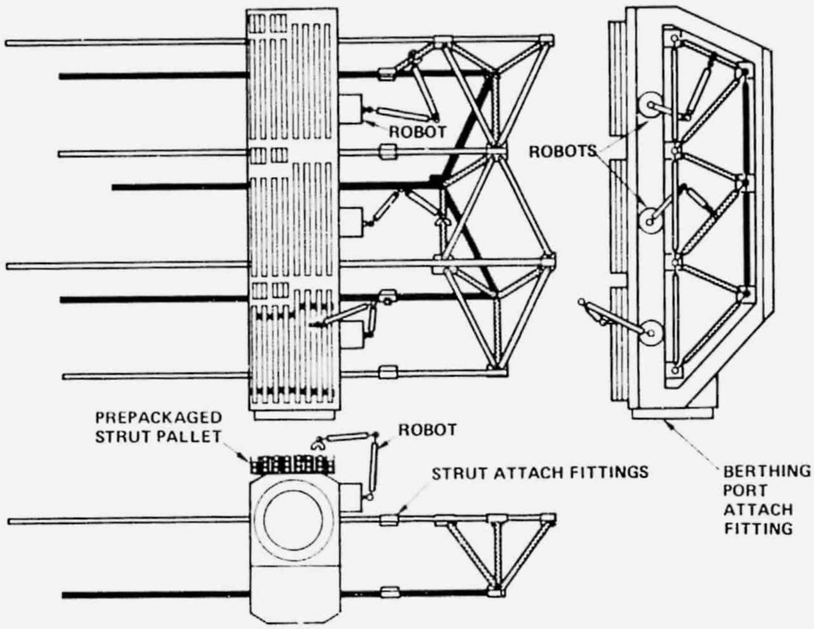

Figure 4-10. Test Article-2 Antenna Universal Truss Assembly Jig

The on-orbit construction of the TA-2 antenna follows the general sequence shown in Figure 4-11. The same assembly tool is used but with the relative position of the automatic feeds and industrial robots adjusted to accommodate the wider antenna support structure. There is also one additional step (not shown) in which an attach fitting and gimbal is installed for subsequent joining to the solar array.

4.5 FABRICATION AND ASSEMBLY REQUIREMENTS SUMMARY

In reviewing construction base requirements, the importance of the crane must be emphasized since it is utilized on all construction projects as well as in both the initial buildup of the base and continuing support of base housekeeping and logistics support. Crane technical requirements, particularly controllability, must be of a very high order. It is therefore believed that a computer-controlled system, similar to launch vehicle or missile autopilot techniques, will be needed. To continue this analogy, in such an autopilot-controlled crane, the human operator provides the guidance signals.

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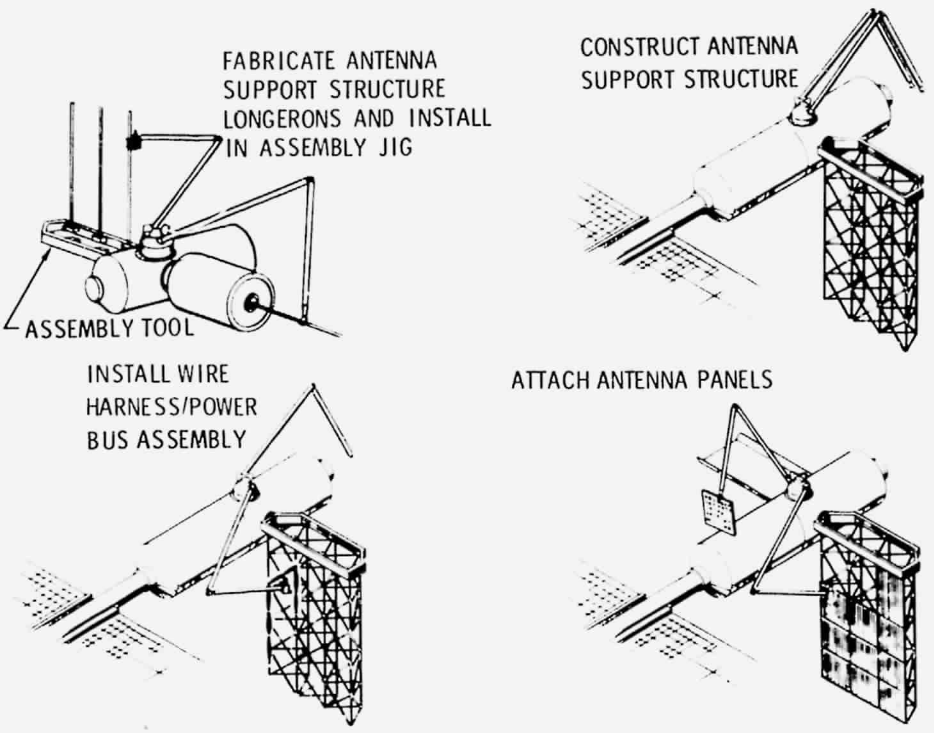


Figure 4-11. Test Article-2 Antenna Fabrication and Assembly Sequence

Control and maintenance support of all construction equipment – together with support of the work crews – will be the primary function of a construction base. Control functions include not only the crane and the various automated construction equipment, but also control of EVA. Since construction activities will necessarily be remote from the control center, a considerable video capability to monitor all active work stations will be needed.

Maintenance provisions, including shop support for minor repairs, will be particularly important because of logistics transport costs. This implies not only a considerable spare parts inventory on orbit but a necessity for careful consideration of maintenance and fault location system requirements during the design phase.

SECTION 5

PROGRAM LEO SYSTEM OPTIONS SYNTHESIS

The configurations described in Section 5.3 used as their baseline requirements the selected objectives and objective elements discussed in Section 5.1 and the integrated requirements discussed in Section 5.2. Section 5.4 contains a discussion of an approach to low-cost module development. Further data are found in Volume 3, Book 2.

5.1 SPACE CONSTRUCTION BASE OPERATIONS ANALYSIS

The overall approach to operations analysis of the various Space Construction Base concepts was: (1) to prepare a detailed mission sequence of each option, (2) to analyze each option to identify critical events and activities, and (3) to study them in greater detail. From these analyses, functional/performance requirements were written.

5.1.1 Preparation of Mission Sequences

The approach taken in Part 2 of the study was to analyze the phase B modular approach to program option L in detail. Three different concepts were studied: (1) an approach using all new module designs, (2) an approach using the modules from phase B as much as possible, and (3) an approach using modules derived from phase B.

As a result of these analyses, several operational areas were identified as being critical and thus were considered in greater depth. These areas were:

- Space Station buildup operations
- Fabrication and assembly operations
- Local Logistics
- Crew size/work shift arrangement

5.1.1.1 Space Station Buildup

The buildup of a modular space station must be accomplished within the constraints imposed by the Shuttle Orbiter in the areas of docking, berthing,

RMS operation, and stability and control. The resultant configuration also must provide a convenient arrangement for operations. Development of such a configuration required carefui analysis of each event during buildup while looking ahead to the final operational configuration.

Figure 5-1 is typical of the mission sequences that were prepared for each configuration. Figure 5-2 presents a summary of the SCB buildup of the program option configuration using the Phase-B derivative module approach. In deriving the mission sequences shown in Figures 5-1 and 5-2, a number of requirements were derived as noted in Table 5-1. The requirement for the crane is considered further in Volume 3, Book 2. The requirement for unmanned duration (Requirement No. 4 as shown in Table 5-1) and 10 day on-orbit checkout time (Requirement No. 11) are predicated on the timeline presented in Figure 5-3. With the 4-1/2 week checkout time, the possible impact that installation in the Orbiter along with mission kits (e.g., airlock/ docking tunnel) might have on Shuttle turnaround time, and the desire to limit the number of GSE shipsets, launching any sooner than every other week is probably impossible. Since 5 launches are needed for the configuration in Figure 5-2 before first manning, at least 2 months are spent in an unmanned mode – a factor of 2 on this results in the 4-month requirement for unmanned operation.

5.1.1.2 Fabrication and Assembly Operations

The fabrication and assembly operations were considered in greater detail for several objective elements. Time lines and flows of these operations can be found in Volume 3 for the 30m radiometer, multibeam lens antenna, and SPS TA-1 and TA-2. The requirements for the 30m radiometer (which is typical of a space fabrication job) are presented in Tables 5-2 and 5-3 respectively.

One aspect of construction which became apparent is the need for significant capabilities at the EVA work station (see Table 5-4 for requirements).

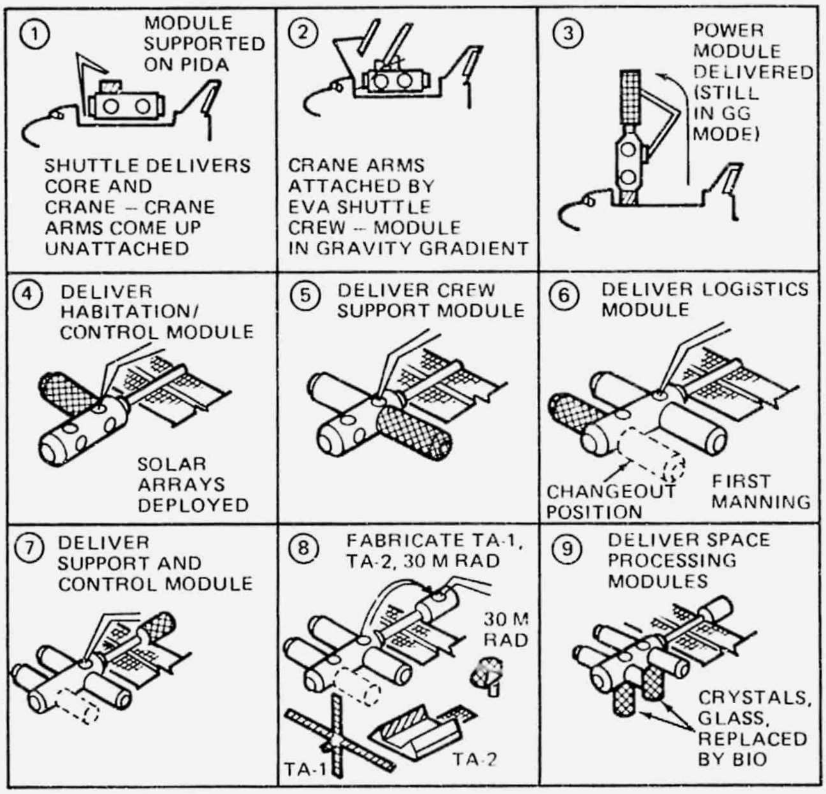


Figure 5-1. Typical Mission Sequence

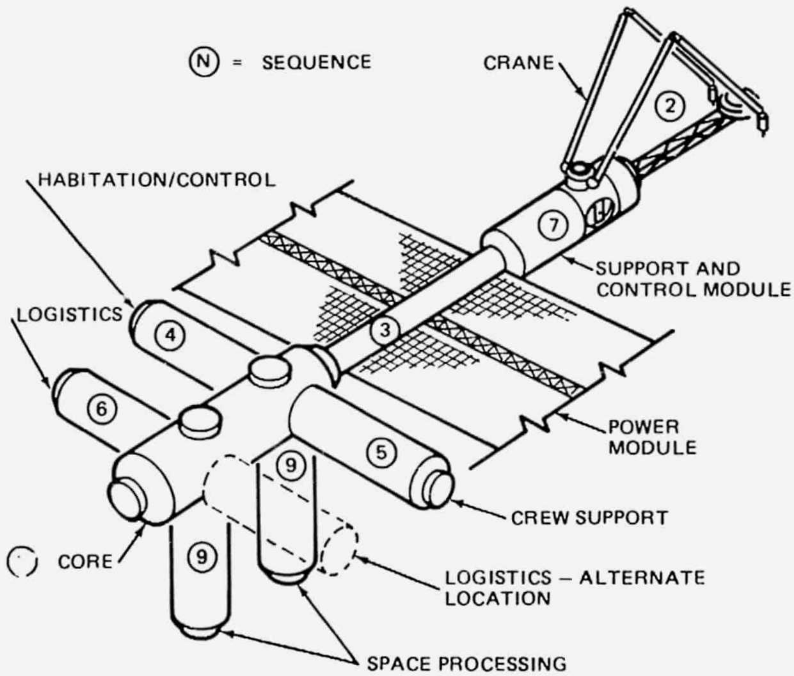


Figure 5-2. Option L Configuration Build-Up, 7-Man Level, Phase-B Derivative Modules

Table 5-1

SPACE CONSTRUCTION BASE BUILDUP REQUIREMENTS

1. The buildup sequence of modules shall be as indicated in Figures 5-1 and 5-2.

2. The sign convention for the Space Station shall be as shown in Figure 5-1.

3. A crane shall be provided to assist in buildup
   - Crane shall be operable from an operator station within the crane for emergency operations and during buildup.
   - Assembly crane shall be able to maneuver modules to a port and perform terminal rendezvous and docking/berthing.
   - TV lights and cameras shall be located to provide universal view of Space Construction Base and depth perception function to the crane operator.

4. Space Station shall be able to operate unmanned up to 2 months.

5. The berthing mode shall be used for buildup (Shuttle docks to -X-axis port and Shuttle RMS or Space Construction Base Crane modules berth to the appropriate port).
   - One port shall be left open for module changeout.
   - Shuttle shall be able to berth modules to any side port on core.
   - All berthing ports shall seal for manual connection of services.
   - TV aids for berthing shall be available at each berthing port.

6. The station shall be capable of operating with solar array panels fixed in the XY plane for (TBD) orbits for assembly maneuvers.

7. The station-Shuttle combination shall be capable of stable operations while docked for up to 5 days.

8. The following constraints on configuration shall be considered:
   - Fabrication and assembly activities should be isolated from crew habitability area in terms of noise and other disturbances.

Table 5-1

SPACE CONSTRUCTION BASE BUILDUP REQUIREMENTS (Continued)

- "Permanent" modules should be placed at forward ports (along X-axis) of the station and on +Z-axis ports.
- An open corridor in the XZ plane in the -Z direction shall be provided for module transport about the station.

9. Remote command from the Shuttle shall be provided during assembly:
   - To command the station to a stable configuration for rendezvous and docking during buildup.
   - To deploy solar arrays.
10. The SCB must be capable of crew entry while attached to the Shuttle during buildup.
11. Individual module checkout should be accomplished in 10 days to allow launches on two week centers during buildup.

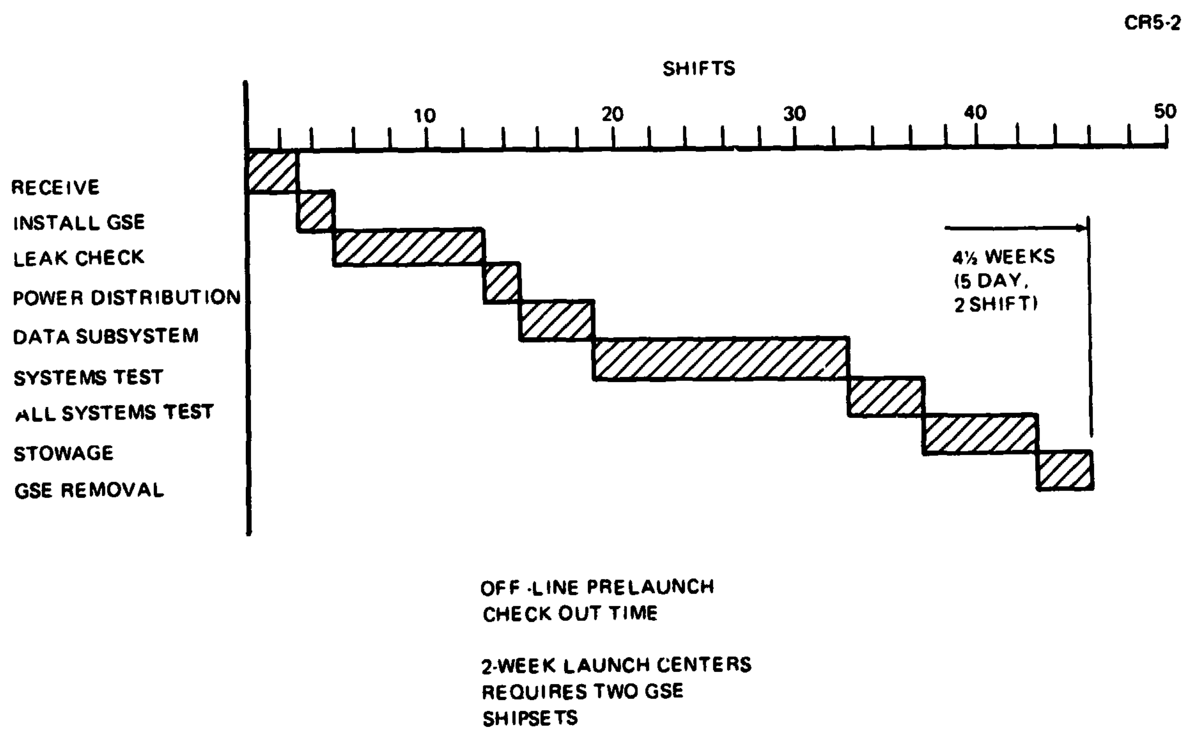


Figure 5-3. Typical Module Ground Checkout Time – Construction Base Build-Up

Table 5-2

30M RADIOMETER CONSTRUCTION

1. A crane shall be provided to assist in assembly operations.
   - The crane shall be capable of retrieving parts/subassembling from the canister of up to TBD lbs and 20m length positioning parts/subassemblies to within TBD cm of final position.
   - The crane shall be capable of being remotely controlled by EVA crewmen from portable controller.
2. Selected final positioning and assembly operations shall be performed by EVA crewmen.
   - EVA crewmen shall be provided aids to assist them in final positioning of parts/subassemblies.
   - Semiconfined quarters at each work position shall be available for EVA operations.
   - EVA/Airlock capability for two crewmen shall be provided.
   - Voice communications and visual surveillance of EVA crewmen shall be provided.
3. Diffuse light shall be provided at each work position to provide low contrast lighting during both dark and light periods of the orbit.
4. The capability to rotate the structure 360 degrees in one plane shall be provided during assembly.
5. TV surveillance of assembly operations shall be provided.
6. Precision alignment capability shall be provided.
   - Precise alignment tools shall be provided to provide range and angle between benchmarks, up to 15m apart to within ± TBD mm and TBD arc seconds.
   - Capability for precision installation of radiometer and electronic components shall be provided by means of portable jigs, alignment fixtures, etc.
7. Safety precautions shall be of paramount importance during wheel spin-up tests.

Table 5-2

30M RADIOMETER CONSTRUCTION (Continued)

8. Umbilical and/or RF link between station and satellite shall be provided for satellite and systems activation (e. g. , solar array deploy) and checkout while still attached.

9. Means of fill and vent of the satellite shall be provided.

   - Filling of satellite working fluid/gases shall be provided by means of portable fill lines.
   - Loading operations shall be controlled from the station.
   - Redundant methods of venting lines prior to removal from the satellite shall be provided.
   - Remotely commanded disconnect shall be provided.

Table 5-3

TEST ARTICLE-2 CONSTRUCTION AND FINAL ASSEMBLY

1. A crane shall be provided to assist in assembly operations.

   - The crane shall be capable of retrieving parts/subassembling from the canister of up to TBD lbs and 20m length positioning parts/subassemblies to within TBD cm of final position.
   - The crane shall be capable of being remotely controlled by EVA crewmen from portable controller.

2. Selected final positioning and assembly operations shall be performed by EVA crewmen.

   - EVA crewmen shall be provided aids to assist them in final positioning of parts/subassemblies.
   - Semiconfined quarters at each work position shall be available for EVA operations.
   - EVA/Airlock capability for two crewmen shall be provided.
   - Voice communication and visual surveillance of EVA crewmen shall be provided.

3. Diffuse light shall be provided at each work position to provide low contrast lighting during both dark and light periods of the orbit.

Table 5-3

TEST ARTICLE-2 CONSTRUCTION AND FINAL ASSEMBLY (Continued)

4. A method (e. g. crane) shall be provided to hold the completed TA-1 assembly for cut, trim and closeout operations.

5. Precision alignment capability shall be provided.

   - Precise alignment tools shall be provided to provide range and angle between benchmarks, up to 15m apart to within ± TBD mm and TBD arc seconds for mandrel assembly.

   - Methods of checking and correcting beam alignment during fabrication shall be provided; total deflection of a single beam shall not exceed 0. 5m.

6. Automatic control of reels shall be provided to assure identical manufacturing rate on all beam caps (within TBD m/sec).

7. Beam cap makers shall be capable of being replaced during fabrication.

8. Storage for three beam trusses (30 x 10m triangle) and a 9 x 15m antenna assembly during construction shall be provided.

9. Communications link to Space Construction Base shall be provided for checkout of TA-1.

10. The Space Construction Base attitude control system shall be capable of accommodating TA-1 during manufacturing.

11. The capability to install and align active sensors during manufacturing shall be provided to furnish control signals for the Space Construction Base control system during manufacturing (requires link to base).

Table 5-4

EVA WORK STATION REQUIREMENTS

1. An EVA work station shall be provided at each EVA work position.

2. The EVA work station shall provide the following:

   - Support for 2 EVA crewmen.
   - Force-torque reaction to allow hand positioning of parts with inertias up to TBD kg sec^2/m.
   - Small parts/tools storage.
   - Crew foot and waist restraints and handholds.
   - Communications to the Space Construction Base; voice, data entry, and display.
   - Surveillance TV of work and crewmen.
   - Portable/adjustable angle lights.
   - Services for power tools; electric and pneumatics.
   - A work area approximately 2.5 x 1.5 x 1.5m.
   - Safety constraints/mechanisms to preclude accidental damage of mission hardware during positioning of the work station.

Figure 5-4 presents an EVA work station using a cherry picker platform which would be mounted on the end of a crane arm. The crewmen would maneuver themselves to the work controlling the crane from the work station.

In the Shuttle-tended mode of operation, assembly operations were analyzed assuming appropriate scaffolding would be available for the EVA work station as indicated in Figure 5-5.

For Shuttle-tended assembly, which uses a strongback and a single RMS-derivative crane, a movable scaffold arrangement is needed. When the SCB becomes permanently manned and a crane is available, a cherry picker platform provides greater flexibility and thus is more desirable.

CR5-2

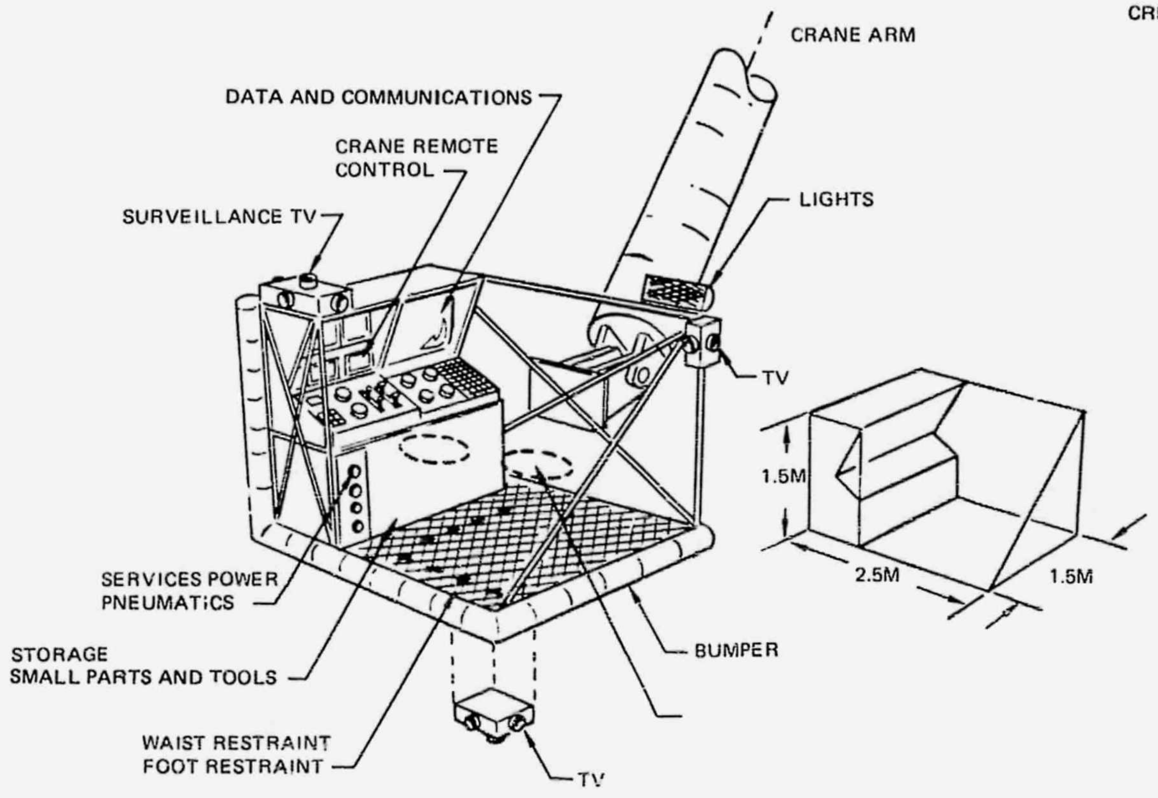
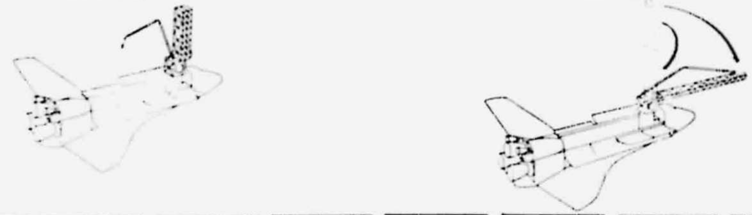


Figure 5-4. EVA Work Station

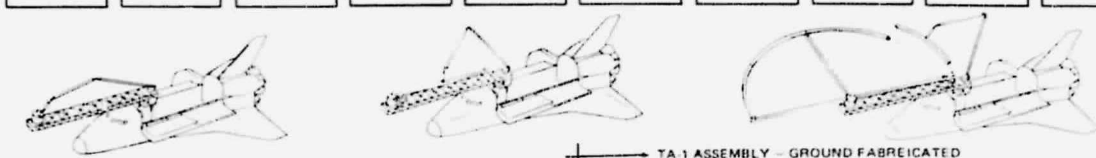
In parallel with the development of EVA work station concepts, analyses were performed to determine total EVA time for any given crewman in a construction job and the resultant exposure to radiation (radiation dose profiles are presented later in Section 6.7.). For fabrication and assembly of TA-1 in the Shuttle-tended mode, assuming a Shuttle changeout every 30 days, each crewman spends a total of 48 EVA hours. As a minimum, this time requires a suit with a thickness of 0.3 gm/cm^2 so the radiation dose will remain within allowable limits. For assembly of TA-1, the EVA time could be as much as 77 hours, for which the 0.3 gm/cm^2 suit would be marginal.

In the permanently manned mode, on-orbit stay times become greater. For TA-1, a given crewman would spend 144 hours EVA in a 90-day period, requiring approximately 0.4 gm/cm^2 of shielding. As construction jobs become more extensive, the radiation problem becomes more acute. As an example, for TA-2 (to be discussed later), a single crewman would spend 336 hours EVA in a 180-day period and would require approximately 0.5 gm/cm^2 of shielding.

DELIVER STRONG-BACK AND RMS CRANE → SHUTTLE RMS TRANSFER STRONG-BACK TO DOCKING MODULE → ACTIVATE AND CHECKOUT CRANE RMS → DEPLOY TV AIDS AND LIGHTS → DEPLOY STRONG-BACK → CHECK OUT STRONGBACK AND RELEASE → SHUTTLE RETURN → DELIVER 30M RADIO-METER PAL-LET DOCK TO STRONG-BACK → ACTIVATE TV LIGHTS AND RMS CRANE → RETRIEVE SATELLITE ASSEMBLY FROM BAY

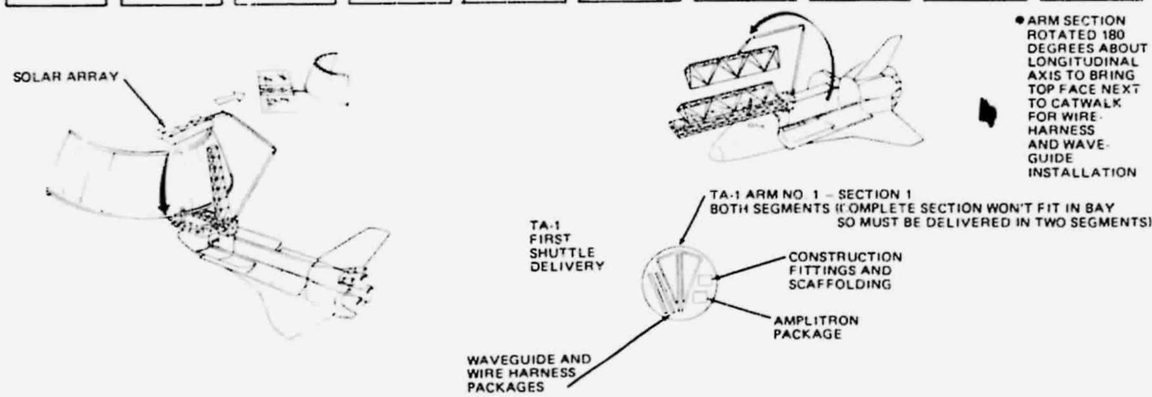


CREWMEN TRANSFER TO TURN-TABLE AREA → RMS CRANE TRANSFER SATELLITE TO TURN-TABLE → EVA CREW-MEN MAN-EUVER SATELLITE AND CLAMP TO TURN-TABLE → INSTALL CROSS BEAM NO. 1 TO HUB ASSEMBLY ON SATELLITE → ATTACH FRAME SECTION,EVA CREWMEN AT STRONGBACK BASE → ROTATE HUB 90 DEGREES ATTACH BEAM NO.2 → ATTACH FRAME SECTION → ROTATE 45 DEGREES AND SE-CURE FRAME TO FRAME-JOINT → ROTATE 35 DEGREES AND IN-STALL BEAM NO. 3 → ATTACH FRAME SECTION



TA-1 ASSEMBLY – GROUND FABREICATED AND ASSEMBLED ANTENNA ARMS EACH ARM MADE OF 3 SECTIONS EACH WITH 2 SEGMENTS

INSTALL SOLAR ARRAY MAST AND DRIVE → LOAD CON-SUMABLES → PERFORM ALL SYSTEMS CHECKOUT → SEPARATE 30M RADIO-METER → REMOVE 30M RADIO-METER SCAF-FOLDING → DELIVER TA-1 ARM NO.1 SECTION NO. 1 → INSTALL FIRST ARM SEGMENT ON STRONG-BACK → PLACE SECOND ARM SEG-MENT ON FIRST → EVA CREW IN CAT-WALK SECURE APEX FITTINGS → REVERSE TA-1 ARM NO. 1 ON STRONG-BACK



ROTATE -35 DEGREES AND SECURE FRAME TO FRAME-JOINT → ROTATE -35 DEGREES INSTALL LONGERON → ERECT EVA SCAF-FOLDING → INSTALL TOP FRAME SECTIONS → ROTATE ASSEMBLY AND INSTALL WHEEL ASSEMBLY (EVA AT HUB) → INSTALL ALIGN-MENT TOOL → ROTATE HUB 104 DEGREES AND INSTALL PARABOLIC PANEL → ROTATE HUB IN 14 DEGREE INCREMENTS AND IN-STALL PANELS → INSTALL EQUIPMENT ON WHEEL → INSTALL SCAF-FOLDING FOR SOLAR ARRAY INSTALLA-TION

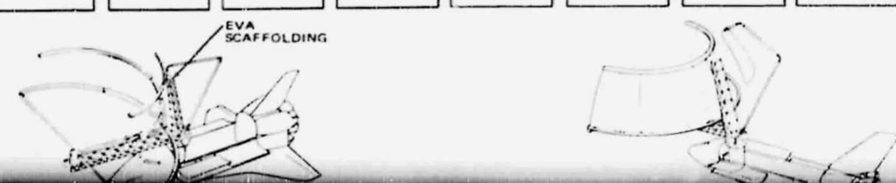


Figure 5-5. Shuttle-Tended Assembly Operations

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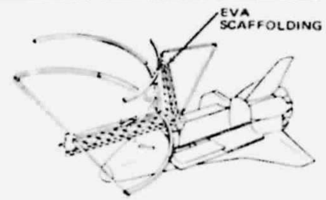
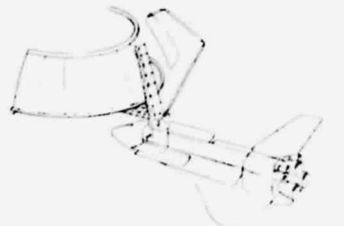
FOLDOUT FRAME

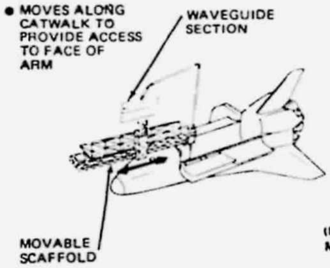
- ROTATE -35 DEGREES AND SECURE FRAME TO FRAME-JOINT
- ROTATE -35 DEGREES INSTALL LONGERON
- ERECT EVA SCAFFOLDING
- INSTALL TOP FRAME SECTIONS
- ROTATE ASSEMBLY AND INSTALL WHEEL ASSEMBLY (EVA AT HUB)
- INSTALL ALIGNMENT TOOL
- ROTATE NUB 104 DEGREES AND INSTALL PARABOLIC PANEL
- ROTATE HUB IN 14 DEGREE INCREMENTS AND INSTALL PANELS
- INSTALL EQUIPMENT ON WHEEL
- INSTALL SCAFFOLDING FOR SOLAR ARRAY INSTALLATION

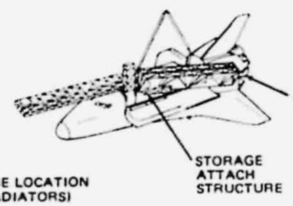


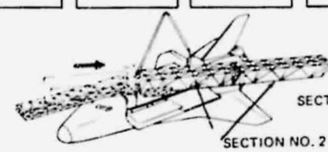


- INSTALL MOVABLE SCAFFOLD
- ATTACH WIRE HARNESS ASSEMBLY
- ATTACH WAVE GUIDE ASSEMBLY AND AMPLITRONS
- INSTALL ARM STORAGE ATTACH STRUCTURE
- TRANSFER ARM TO STORAGE ATTACH STRUCT
- DELIVER ARM NO. 1 SECTION NO. 2
- ASSEMBLE SECTION NO. 2 AS DONE IN NO. 1
- ERECT SECTION JOINING SCAFFOLDING
- JOIN SECTION NO. 2 TO SECTION NO. 1
- TRANSLATE SECTION NO. 1 & NO. 2 AFT TO CLEAR STRONG BACK

● MOVES ALONG CATWALK TO PROVIDE ACCESS TO FACE OF ARM



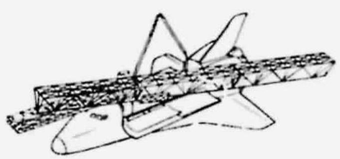


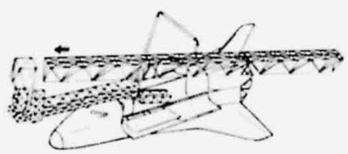


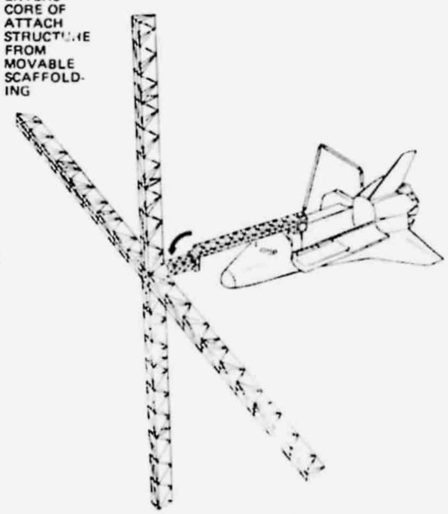
(NOTE: STORAGE LOCATION MAY IMPACT RADIATORS)

- DELIVER ARM NO. 1 SECTION NO. 3
- ASSEMBLE SECTION NO. 3
- JOIN SECTION NO. 3 TO SECTION NO. 2
- DELIVER TA-1 SATELLITE-SOLAR ARRAY MODULE
- INSTALL SATELLITE ON TURNTABLE
- RELEASE ARM STORAGE CLAMPS
- MOVE ARM NO. 1 TO SATELLITE AND ATTACH
- ROTATE ARM OUT OF THE WAY
- ASSEMBLE ARMS 2, 3, AND 4 IN SIMILAR FASHION
- TILT TURN TABLE 90 DEGREES ABOUT Y-AXIS AND INITIATE TESTS

● EVA TASK CREWMAN ENTERS CORE OF ATTACH STRUCTURE FROM MOVABLE SCAFFOLDING







In view of the foregoing, the protection provided by the current Shuttle EVA suit must be increased by at least a factor of 3 by the 1984-1985 time frame. Our subcontractor, Hamilton Standard, has indicated that concepts for such a suit are available and apparently present no insurmountable difficulties. As EVA types of jobs become more extensive, the amount of shielding required becomes impractical for suits, and either shorter careers are indicated for crewmen or enclosed work stations are needed. Two concepts are: (1) a hard-suit cherry picker in which man works from a pressurized cabin through a glove box, and (2) a pressurized cabin with remote manipulator arms. The above concepts are illustrated in Figure 5-6.

5.1.1.3 Local Logistics

In the analysis of Space Station buildup and construction operation, the need to move men modules and materials about external to the station, became apparent. Accordingly, this local logistics problem was considered in some depth and is reported in Volume 3. A manned minitug concept was considered

CR5-2

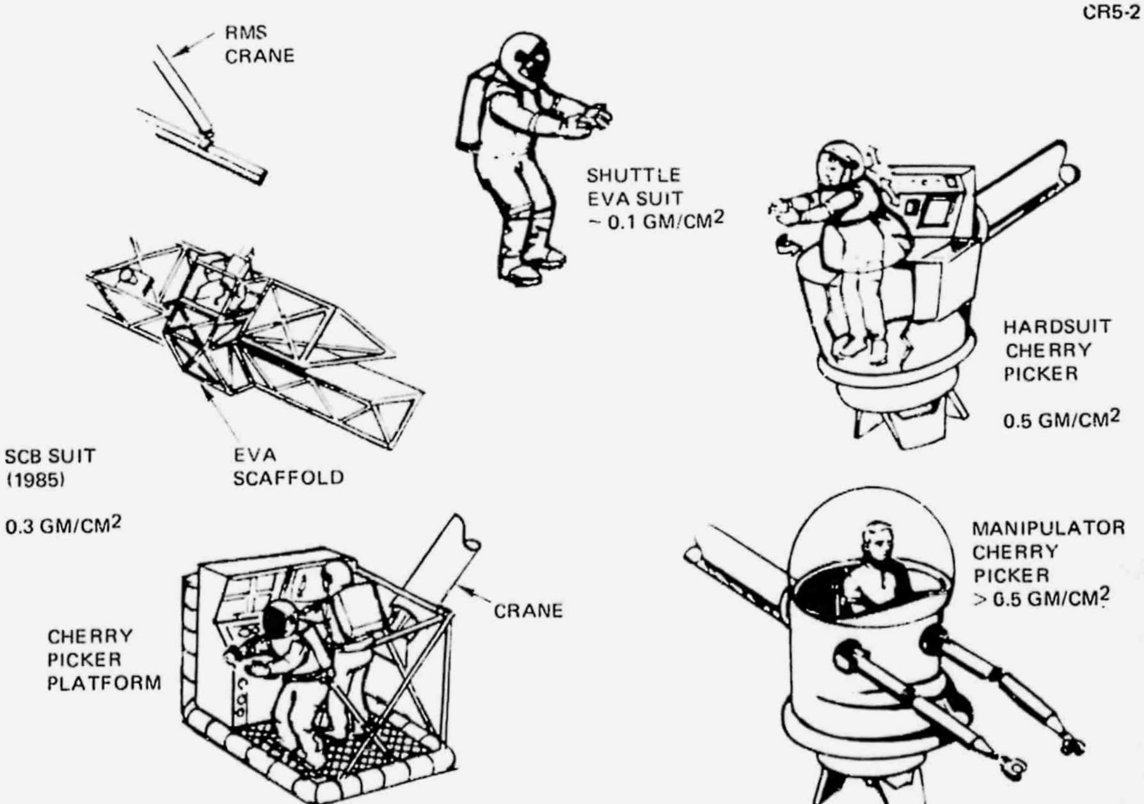


Figure 5-6. EVA Work Station Concepts

with the crane considered in both a fixed and a mobile configuration. The requirements of the crane operations are presented in Table 5-5.

Table 5-5

CRANE OPERATIONS

1. The crane shall have two independent arms for support of assembly operations; a single arm crane shall be provided for buildup and module maneuvering.
2. The crane shall be able to manipulate and berth modules up to 25,000 kg (55,000 lbm) and 15.2m (50 ft) long.
3. The crane shall be able to manipulate and position assembly parts up to TBD m and 19.8m (65 ft) long.
4. A 35m reach shall be provided.
5. 7 degrees of freedom shall be provided:
   - Crane Body (yaw)
   - Should Joint (pitch and yaw)
   - Elbow Joint (pitch)
   - Wrist Joint (pitch, yaw, roll)
6. Arm tip force capability shall be 89n (20 lbf).
7. Vernier control for fine positioning shall be provided.
8. TV camera and lights shall be on each crane arm.
9. The crane operator shall be provided an unobstructed view of the crane's spatial volume (direct and/or TV assisted).
10. Collision avoidance software and/or maximum torque override shall be incorporated in the crane.
11. Automatic joint lock in case of joint motor failure shall be provided.
12. Remote control of the crane from EVA work stations shall be provided.

The capabilities of both the mobile crane and the minitug have advantages for a large SCB since they both:

A. Allow module replacement w/o disassembling the SCB
B. Do not require an open corridor on the SCB
C. Can accommodate SCB growth
D. Can move out onto large construction
E. Provide greater visibility for the operator

Between the mobile crane and the minitug, there is little to choose in terms of capabilities. There may, however, be a considerable difference in terms of efficiency of energy usage. The minitug would be carrying its payload to greater distances from the SCB cg, and thus encountering more orbital effects. The thrust required to counteract these effects would be magnified by the necessity to avoid induced rotation (see Section 2. 1). As a result the minitug becomes most inefficient in its energy usage. Another point favoring the mobile crane in this regard is that it can be operated using electrical energy available through the SCB solar arrays. Fuel for the minitug would have to come out of Shuttle payload weight. On the other hand, the mobile crane could also require fuel indirectly through its effect on the SCB control system. Reaction forces and moments imparted to the SCB by the crane would have to be removed. This is an area which will need a good deal of study before any definitive conclusions can be drawn.

5.1.1.4 Crew Size/Work Shift Arrangement

With construction having high priority, a primary driver in establishing total crew size is the basic construction crew complement, which was found to be three men: two men EVA and one manned operating the crane.

It was determined that the more efficient utilization of construction crewmen results if they are used on a multiple shift basis with current indications being that a two 10-hour shift operation is optimum. This is discussed in detail in Volume 3, Book 2. For construction, such an operation would require six men on the station. Examining other activities such as cargo transfer, food preparation, general cleaning, and maintenance revealed that a number of them could be handled by the construction crewmen as added off-hour tasks (e. g. , each crewman would cook his own meals or draw

housekeeping duty.) Also, the construction crane operator could monitor station functions. The primary effort, which could not be handled by the construction crew, would be maintenance activities (4 to 7 hours per day), thus an additional man is needed — this results in a 7-man crew. Using this crew increment and the priorities and constraints noted on the facing page, schedules can be prepared for the permanently manned SCB.

For the Shuttle-tended mode, considerations were made of volume available for work, sleep, eating, etc. to establish a reasonable crew size.

Based on information received from NASA[1], the estimated combined free volume of the Shuttle flight — deck and mid-deck sections is $28m^3$. Free volume, as discussed in this document, is defined as the space available in a specific location for body movement and transfer within the location, ingress to and egress from the location, and performance of tasks at the location.

With a basic crew complement of seven (3 flight crew and 4 support personnel), the Shuttle free volume per crewman is $4m^3$. Based on experimental free volume — duration tolerance in confinement data[2], this represents an acceptable value when 30-day missions are considered. For mission durations greater than 30-days, applicable experimental data is very limited and, consequently, a meaningful data base for extrapolating volume requirements is not available. The data do indicate, however, that with the free volume per crewman of $4m^3$, detectable crew impairment may occur if longer mission durations and larger crews are considered. On this basis it is recommended that the minimum free volume allocation per crewman should range between $5\text{-}6m^3$ for missions greater than 30 days, to provide an acceptable crew confinement tolerance level. For a crew of seven, this would equal to a total Shuttle free volume requirement of $35\text{-}40m^3$.

To support a Shuttle tended Space Construction Base, where the crew duty cycles are based on two overlapping 10-hour shifts per 24-hours, the crew complement increases to 9 to 10 crewmen. Therefore, for missions of

1. Telecon, A. T. Pessa to Robert T. Gundersen, Crew Systems, NASA-JSC, Houston, Texas, dated 2-4-77
2. Fraser, T. M., The Effects of Confinement as a Factor in Spaceflight, Washington, E. D., 1966.

greater than 30-days duration, the total Shuttle free volume allocations should be as follows:

Crew Size	Required Orbiter Free Volume Range (m^3)
7	35 - 40m^3
9	47 - 51m^3
10	50 - 57m^3

The Shuttle flight – deck and mid-deck sections are capable of providing only 28m^3 of free space. Increased free space might be provided by other means. Depending on the crew size, the additional approximate free-volume requirements are: (1) 7-man crew – 6 - 11m^3; (2) 9-man crew – 16 - 23m^3; and (3) 10-man crew – 21 - 28m^3.

5.2 INTEGRATED PROGRAM OPTION REQUIREMENTS

Program option requirements were developed using schedules for objective element accomplishment. With these schedules, requirements were summarized and integrated as a function of time. The results were then timelined and portrayed in the form of resource consumption profiles. Maximum levels picked from the profiles established the baseline requirements and objective-element peculiar requirements to form a complete requirements set.

Schedule variations were analyzed by constraining the number of crewmen available, changing the order of objective element accomplishment, varing the rate of objective element accomplishment, and varying the location (LEO to GEO) of objective performance. The analyses were performed in an iterative fashion, i.e., levels of resource consumption or program durations were assigned and resultant SCB configurations were observed. New schedules were developed to optimize or reduce certain characteristic requirements on the SCB itself, and were also varied (reduced) by assuming levels of support available from the Orbiter. In this case, only a portion of the requirements were levied on the SCB initially. Requirement levels were then gradually increased until Orbiter dependence was eliminated. Using this approach, requirement sets have been developed for a permanently manned SCB supporting seven men performing fabrication and assembly, and test operations.

5.2.1 Object ~~ Element Requirements

Requirements for seven objective elements were defined in terms of orbital characteristics, physical accommodations, crew requirements, environmental conditions, pointing/stability, power, data management, communications, special requirements (airlocks, docking ports, crane requirements, satellites), waste management, and tools/jigs/fixtures. Four quantities were selected as primary configuration drivers which were amenable to profiling on an integrated basis; indeed, required the construction of profiles to determine requirement levels. They consist of crew size, power, pressurized volume, and mass. The crew size, in conjunction with objective accomplishment schedules, determine the sequence of integration of all resources, and particularly, the habitable volume required. Power consumption sizes the solar array/fuel cell system, the radiator area required for thermal control, and indirectly, the module surface area and number of modules needed.

The pressurized volume supplied for objective element support (in conjunction with the free volume provided for the crew), together with the solar array panel area, attached orbiter area, and mass requirements, are necessary to determine stability and control system sizing and fuel expenditure quantities.

Table 5-6 summarizes the requirements for crew and power for the objective elements. Generally, the power required for fabrication and assembly operations are seen to be relatively low with the exception of test requirements for SPS TA-1. The power timeline schedule has taken into account the basic fabrication and assembly operations as well as the test requirements for each objective element. High power requirements are seen for space processing of ultrapure glasses and shaped crystalls. The noted power levels include all power requirements for the space processing modules. Crew requirements shown are for fully dedicated crewmen for the durations of the space processing development phases. Space cosmology requirements, involved with antenna assembly, are identical to those for assembling the radiometry and multibeam lens antennas. Power and crew requirements for living and working in space are small, involving one to two racks of equipment (depending upon the time period in question) and may be performed as other objective element schedules permit. Crew requirements for multidiscipline laboratory R&D are a variable depending upon the priority of the work and the availability of base resources. Sensor development will require two crewmen and 10 kW of average power to meet its objectives.

Table 5-6

OPERATIONAL SUPPORT REQUIREMENTS
PROGRAM OPTION L

Objective Element	Minimum Crew		Power			
			Avg		Peak	
	Fab/Assy	Test	Fab/Assy	Test	Fab/Assy	Test
SPS TA-1	3	1	6 kW	5 kW	10 kW	80 kW (≈0.5 hr)
SPS TA-2	3	2	9 kW	2 kW	12 kW	4 kW
30m Antenna-Radiometry Satellite	3	2	2 kW	2 kW	4 kW	4 kW
27m MBL - Communications Satellite	3	2	2 kW	2 kW	4 kW	4 kW
100m Antenna Radiometry Satellite	4	2	2 kW	2 kW	4 kW	4 kW

SPACE PROCESSING OPTIMIZATION (L)
OPERATIONAL SUPPORT REQUIREMENTS

Space Processing	Minimum Crew	Power	
		Avg	Peak
Bioprocessing	3	4 kW	8 kW
Ultrapure glasses	4	20 kW	30 kW
Shaped crystals	3	12 kW	18.5 kW

ADDITIONAL OBJECTIVE ELEMENT OPERATIONAL
SUPPORT REQUIREMENTS

Objective Element	Minimum Crew	Power	
		Avg	Peak
Living and Working in Space	<1 ('84-'87) <2 ('87+)	0.5 kW → 1.	Not applicable
Multidiscipline Laboratory	1 to 6	2 kW to 12 kW	16 kW
Sensor Development	2	10 kW	12 kW

Total requirements for each objective element may be found in the Program Requirement Document (PRD) Volume 3, Book 1. Requirements not profiled were generally integrated by inspection. In other cases, true integration was not appropriate due to sequential, rather than parallel, objective element performance, or because a requirement was objective-element peculiar.

5.2.2 Schedules

Schedules for objective element accomplishment were generated for all program options which included those in GEO and GEO/LEO, as well as LEO, which were permanently manned. In addition, a number of schedules were generated for Shuttle-tended program options. The schedules were then revised to optimize crew size, reduce "tall pole" resource consumption or to observe the impact on SCB configurations of variations in objective element support. Figure 5-7 illustrates the schedules prepared for Option L, the permanently manned SCB with 7-, 7-14 and 21- man crew constraints.

The 7-man limit permits all space fabrication to be scheduled for completion in early 1987. Only two of the three space processing activities can begin in 1987 with the third one starting in 1991. This schedule does not allow the other activities to begin until 1995. A two- and three-shift operation is used where feasible. Two shifts generally are used in construction activity involving EVA operations because an average EVA work shift, including donning and doffing time, is 10 hours making three-shift operation in a 24-hour day somewhat awkward. Three-shift operations are considered for other activities. The 7-14 man schedule calls for all space fabrication to be completed in early 1987. All three space processing activities and the multidiscipline laboratory activities can begin in 1987. This schedule does not allow the other activities to begin until 1991. The unconstrained (21-man) schedule calls for all space fabrication to be completed in early 1987. All objectives except one of the space processing activities can begin in 1984. The third space processing activity can begin in 1986. This schedule shows all activity complete by the end of 1990.

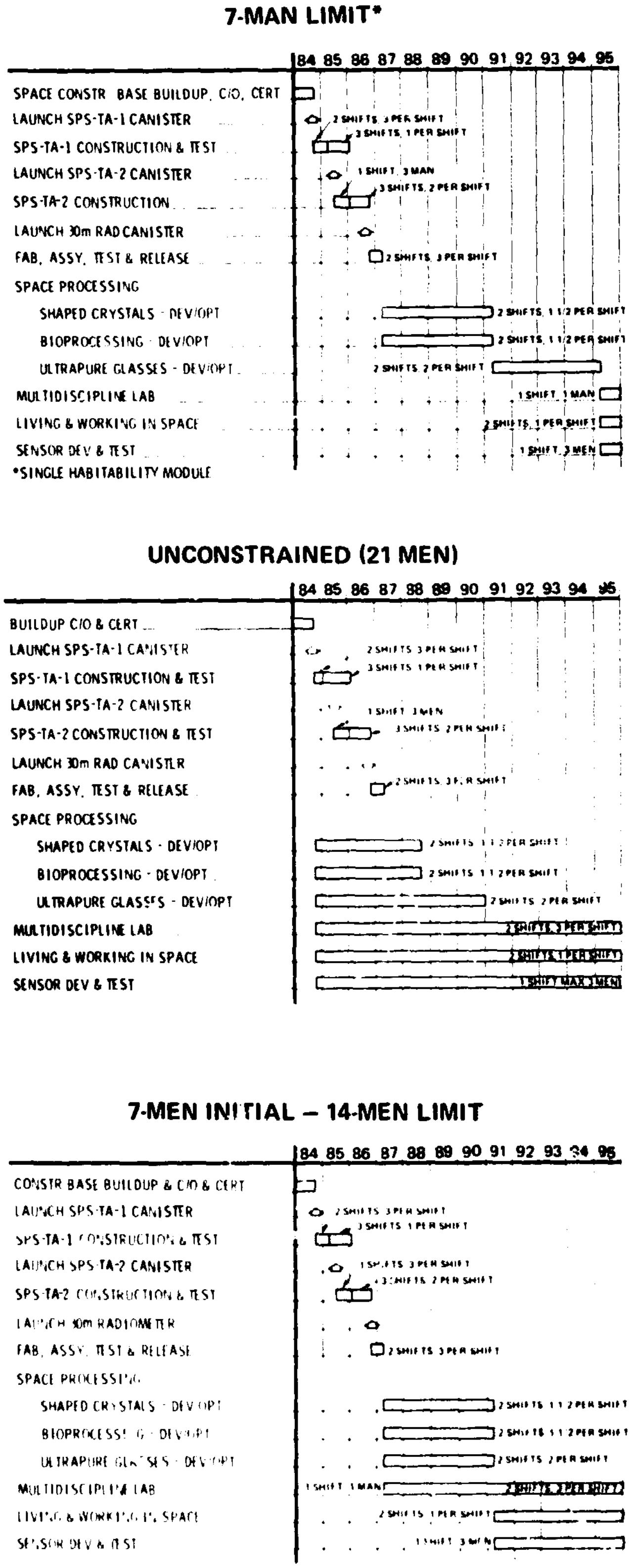


Figure 5-7. Option L

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Figure 5-8 illustrates the final 7-man limit schedule resulting from beginning the multidiscipline laboratory actively concurrently with ultrapure glass processing. The revision results in a more stable crew manning requirement aboard the SCB; 14- and 21-man station schedules were revised in a similar manner.

Figure 5-9 reflects objective element schedules for Shuttle-tended SCB's. It is seen that schedules have been extended commensurate with reduced crew sizes and/or desired SCB capabilities. Each SCB Shuttle-tended schedule, whether it be configured as a simple strongback concept, an SCB employing a reduced-capability stability and control module, or maximum capability SC module is capable of transition to permanently manned schedules by addition of modules and equipment to the Shuttle-tended configuration.

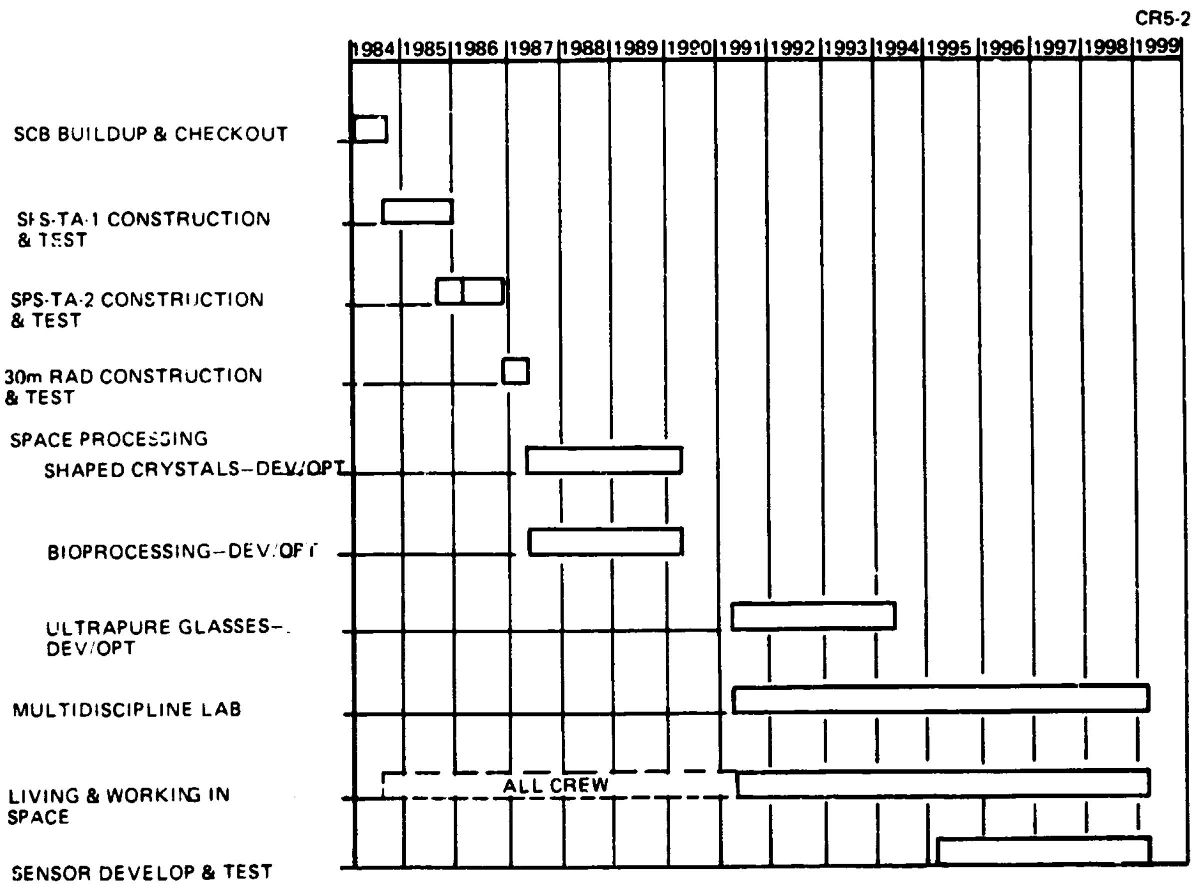
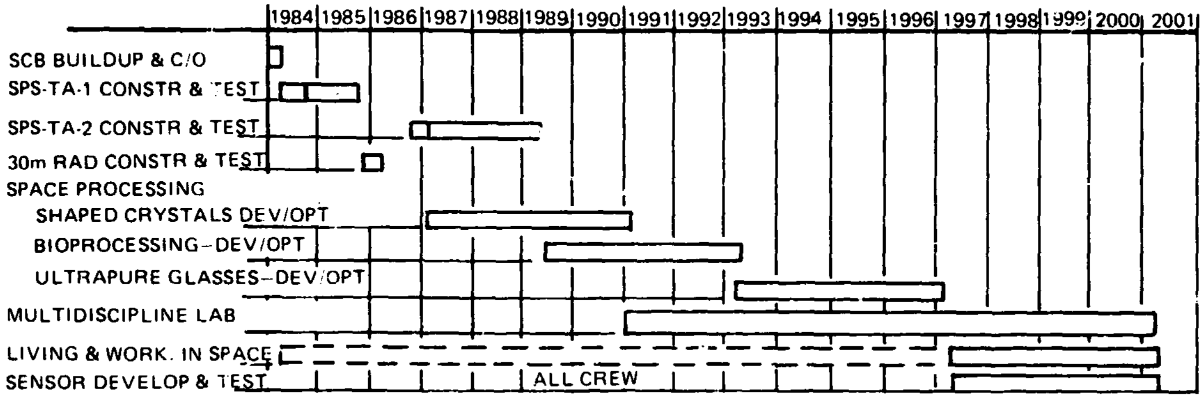
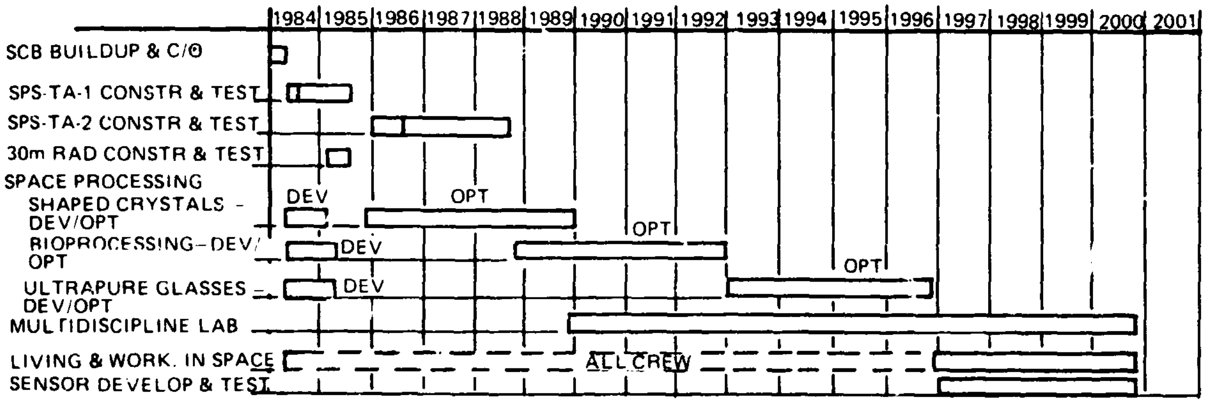


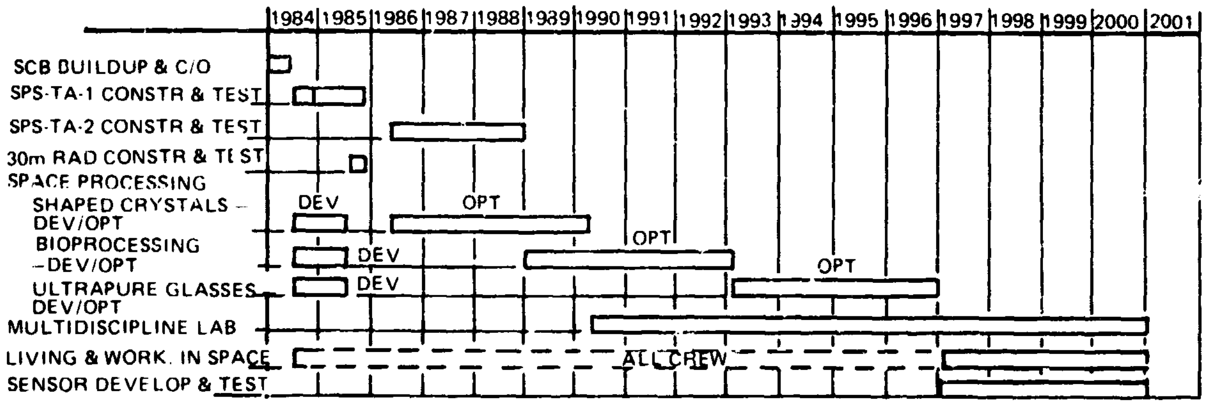
Figure 5-8. SCB Option L – 7-Man Limit



SHUTTLE-TENDED – 3-MAN STRONGBACK CONCEPT



SHUTTLE-TENDED – 7-MAN SINGLE-LAUNCH CONCEPT



SHUTTLE-TENDED – 7-MAN D…ECT-GROWTH CONCEPT

Figure 5-9. SCB Concepts

Using the program option schedules and objective element requirements, integrated requirements profiles were developed. The profiles and schedules were then reviewed, changes made, and profiles revised.

Figures 5-10 through 5-12 illustrate the profiles based on the schedules of Figure 5-7. As a result of the 7-man crew limitation, it is seen in Figure 5-10 that the objective accomplishment has been spread over a longer time period than desirable. Average power is greater than that produced by one array set, which is size-limited to 34 kW by the Orbiter bay. However, requirements may be reduced to the 34 kW limit by proper timelining of hydrogen and oxygen regeneration to occur during nonwork periods.

Resource requirements imposed on the SCB when a schedule for program option development is constrained to a maximum of 14 men is illustrated by Figure 5-11. It is apparent that the level of accomplishment versus function time is quite good, while resource requirements are not excessive, with perhaps one exception – power. Typically, for any configuration, power requirements exceed the capability of one array set whenever a 14-man crew is carried and a corresponding objective task schedule is performed. Two array sets are thus required producing 90 kW (BOL) and 68 kW (EOL). Pressurized volume and mass requirements (for the objective element accomplishment alone) result in a construction base configuration with nine modules.

In the essentially unconstrained case, crew size as shown in Figure 5-12 immediately starts out at 21 men and essentially continues at this level. All resource requirements are seen to be very large during the early operational period resulting in rapid objective accomplishment. Provision for these resources results in a configuration with high drag and torque control requirements.

The result of the schedule optimization work, illustrated by Figure 5-8, is reflected in the profile shown in Figure 5-13. Although the 7-man crew size limitation has been retained, resource requirements generally reflect a more orderly growth and power requirements have been slightly reduced. However, volume requirements are still large during bioprocessing and crystal applications, due to the large amount of support equipment employed.

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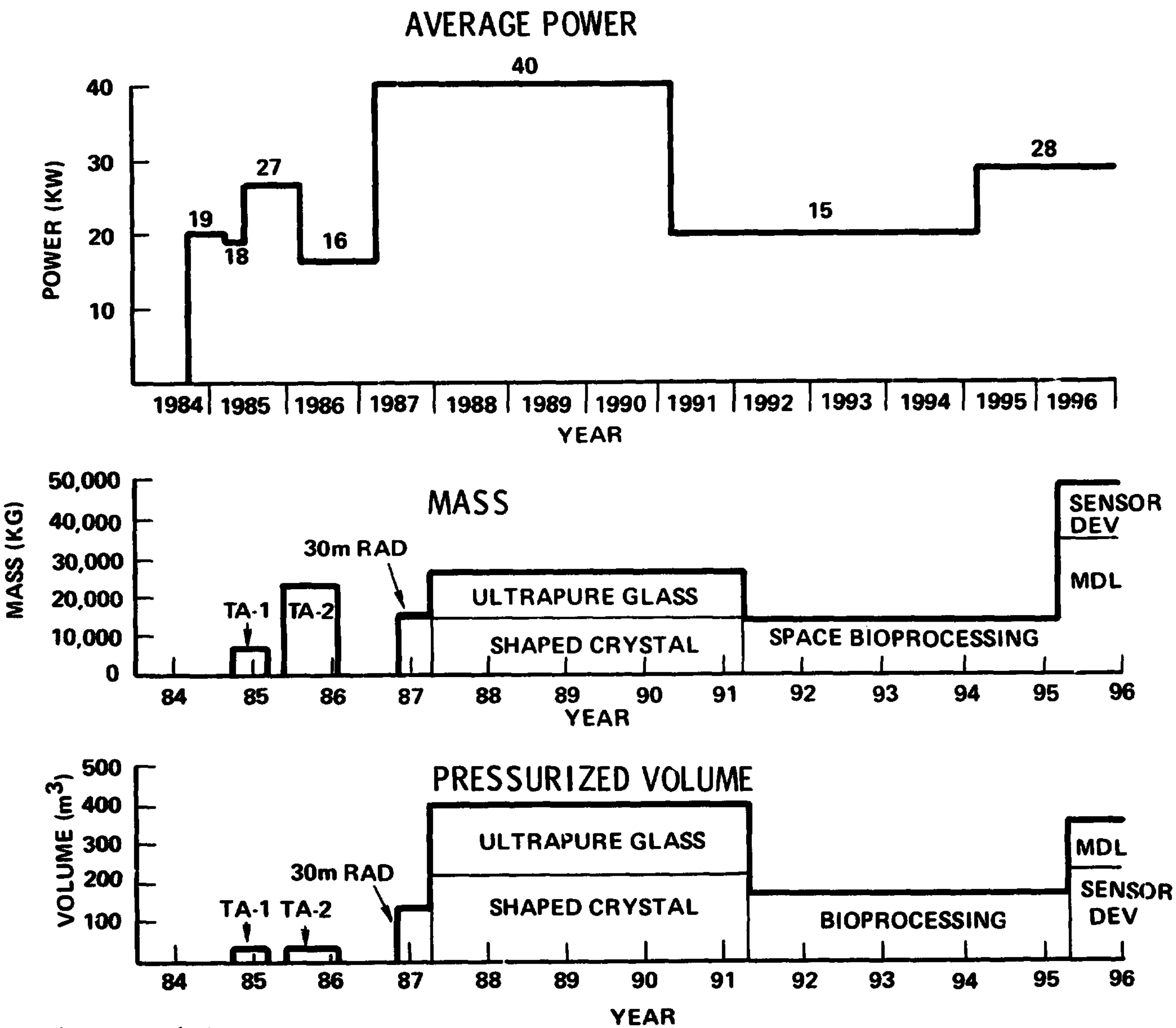

Figure 5-10. Option L (7-Man Limit) SCB Characteristics

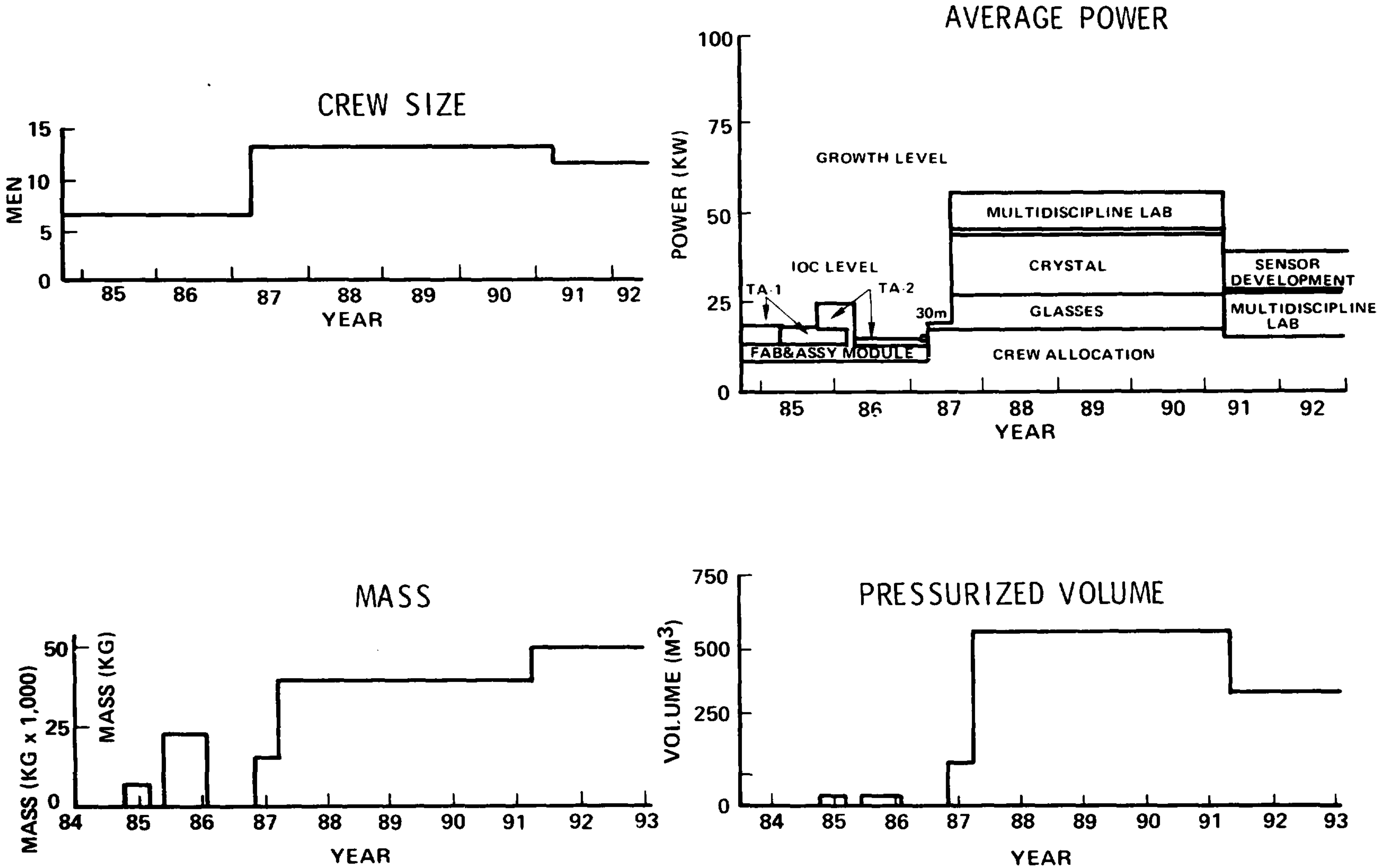

Figure 5-11. Option L (7- to 14-Man Crew) Permanently Manned SCB Characteristics

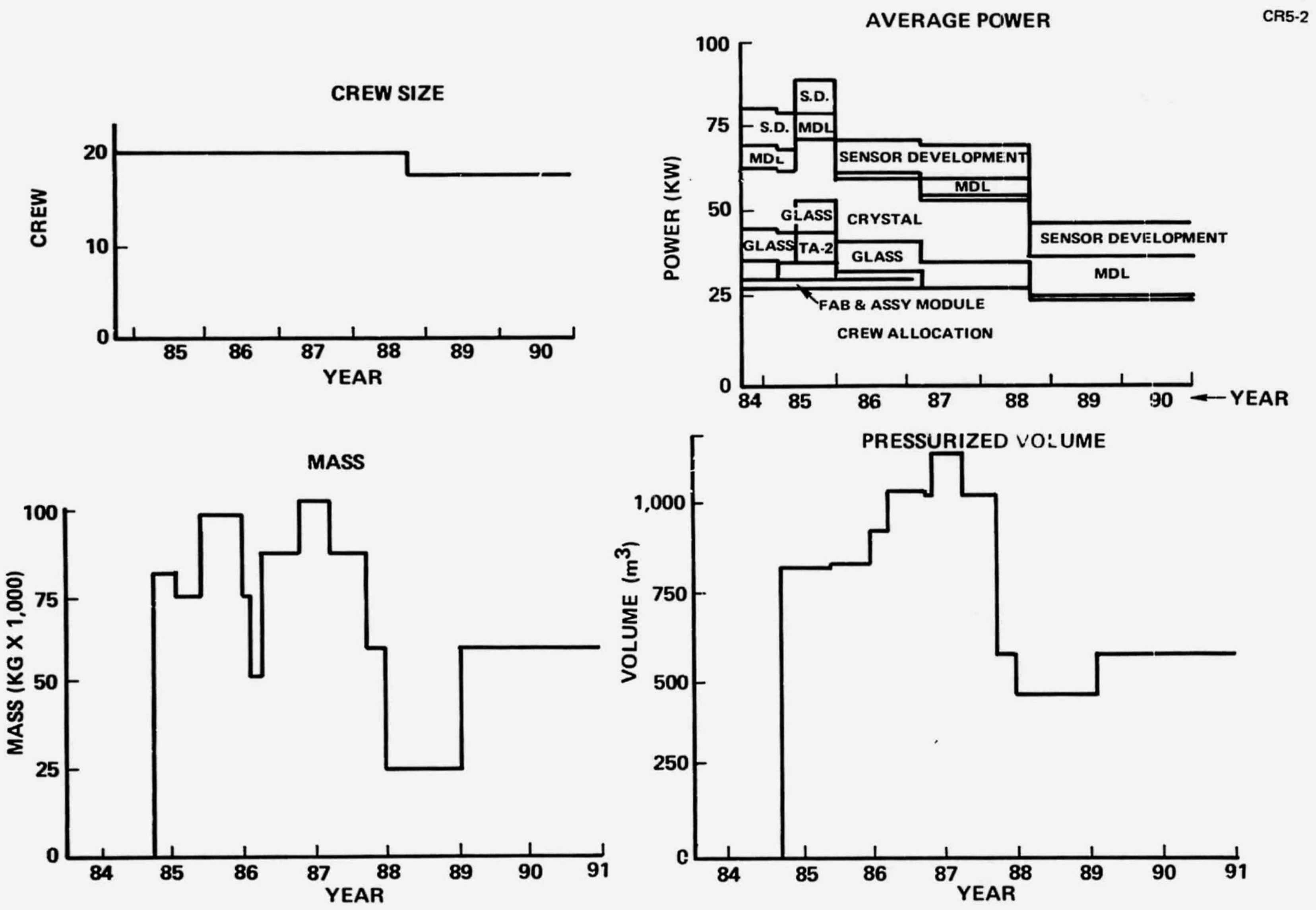

Figure 5-12. Option L (Unconstrained) SCB Characteristics

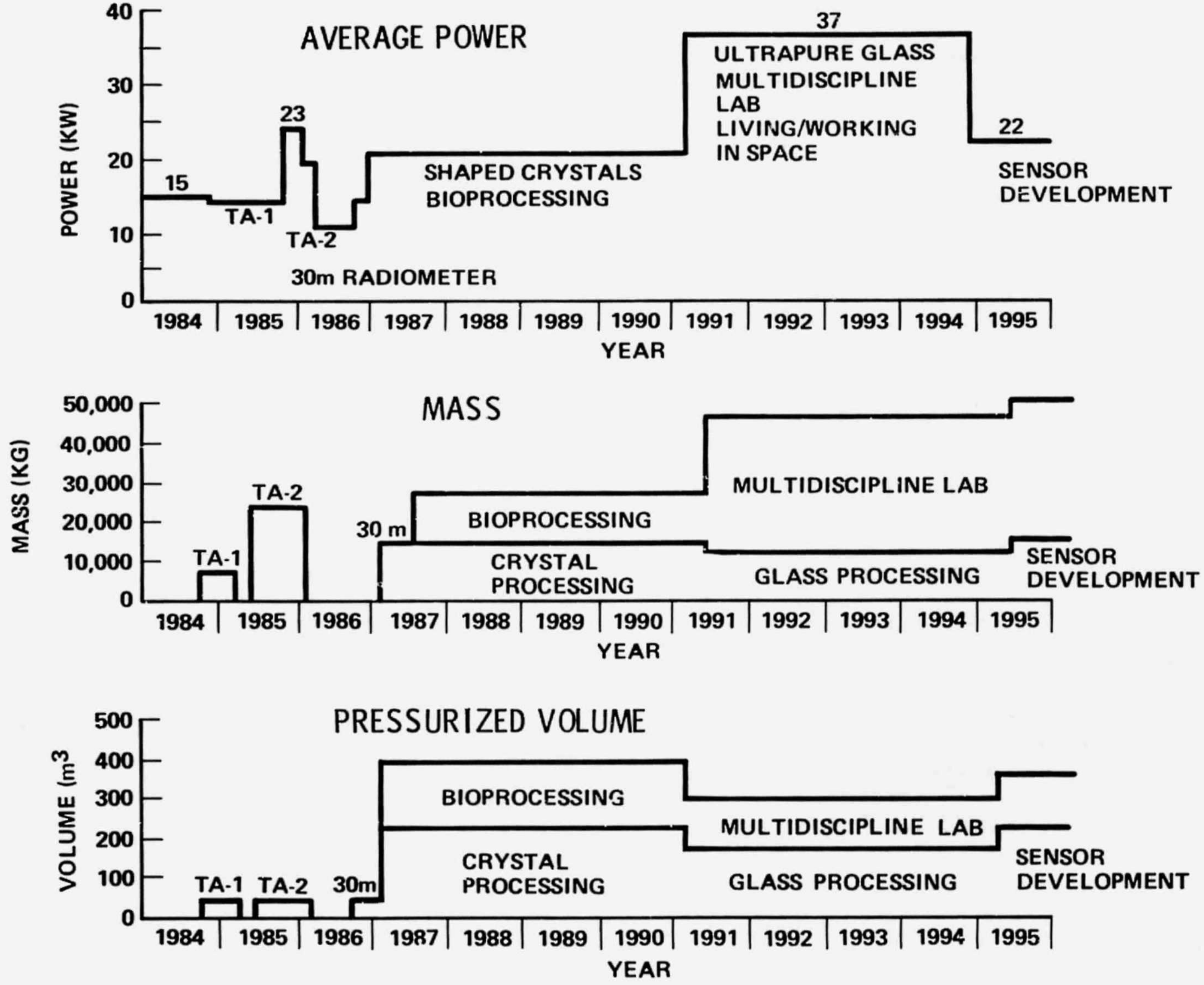

Figure 5-13. Option L (7-Man Limit) SCB Requirements

Profiles were not developed for Shuttle-tended SCB option concepts since it was desired to develop a greater variety in configurations. This was achieved by limiting operations to fabrication and/or assembly of the SPS test articles and assembly of the 30m radiometers. In addition, the objective elements were assumed to be fabricated or assembled in a sequential rather than parallel fashion. Requirements were therefore much reduced and levels were taken to be the maximum required by any one element irrespective of time.

5.2.3 Program Option Requirements

Using integrated measurement levels, objective element requirements in the nondriver category, and general requirements to provide a suitable environment for crew support, a requirement set was developed for a permanently manned SCB. The requirement set, as shown in Table 5-7, also defines the rationale, source or constraints which either contributed to or resulted in the quantitative level of each requirement as appropriate.

5.3 CONFIGURATION DEVELOPMENT – OPTION L'/L

Two basic program options were defined for fabrication and assembly of the objective elements, a Shuttle-tended option and a permanently manned option. The Shuttle-tended (Option L') configurations for the SCB can accommodate crews of from four to seven individuals. Three configurations were developed for the Shuttle-tended option: (1) strongback, (2) single Shuttle launch; and (3) direct growth (Figure 5-14). The three configurations represent different capability levels with regard to growth to permanently manned configurations. Each of these SCB configurations assumes single-shift work activities for a three- to four-man crew living and working from the Orbiter, and two-shift operations with a six- to seven-man crew supported from a separate habitability module provided. The groundrules associated with the Shuttle-tended configurations include the restriction that the maximum duration of the Orbiter docked to the SCB will be 30 days: there will be an allowance of 90 days of SCB free-flight consumables during undocked periods.

The basic three types of configurations evolved from consideration of five different pairs of Shuttle-tended options (L'-1 to L'-10). Each option with an odd-numbered designation (L'-1, L'-3, L'-5, L'-7, and L'-9) is capable of assembly operations only, whereas the even-numbered options are capable

Table 5-7

OPTION L (PERMANENTLY MANNED) REQUIREMENTS

Requirement	Level	Source
General:		
Vehicle orbital life	16 years (min)	SCB Objective element schedule (7-man)
Resupply period	90 days	SCB design guidelines and criteria
Crew size (initial)	7-man	SCB Objective element schedule - 7-man
(final)	14-man	SCB Objective element schedule - 7 - 14-man
Power level (average)		
Bus (IOC)	34 kW	Power profile - 7-man indicates 37 kW, re-scheduling of some loads to nonwork periods should allow reduction
Bus (final)	68 kW	Power profile - 7 - 14-man SCB requires 60 kW. Assume second 34-kW power module added.
Power level (peak)		
Special system	80 kW; 0.5 hr.	Required by TA-1 test. Assumes no bus impact.
Pressurized (initial)	943 m^3 (33,276 ft^3)	Assumes direct-growth configuration; 5-module station growing to 9 modules
(final)	2000 m^3 (70,575 ft^3)	
Unmanned operation	60 days	Operations build-up phase analysis
Stable operation capability with Orbiter docked	5 days	Operations Analysis
Orbital altitude	370 - 650 km (200-350 nmi)	SCB design guidelines and criteria
Inclination	0 - 90 degrees	SCB design guidelines and criteria

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Orientation	All Axes	Minimize sunlight impingement on SPS solar cells
Operational Requirements:		
Environmental Control		
Heat Rejection (initial)	68 kW	Assumes 85% power conversion efficiency; 52% fuel cell charging efficiency; all bus power must be rejected as heat
(final)	120 kW	
Atmosphere	$0_2/N_2$	SCB design guidelines and criteria
Atmosphere total pressure	TBD	SCB design guidelines and criteria
Atmosphere 0_2 partial pressure	TBD	SCB design guidelines and criteria
$C0_2$ partial pressure (nom)	3.8 mm Hg (0.15 in Hg)	SCB design guidelines and criteria
(max)	7.6 mm Hg (0.3 in Hg)	SCB design guidelines and criteria
(contingency)	15 mm Hg (0.6 in Hg)	SCB design guidelines and criteria
Temperature	18° to 27°C (65° to 85°F)	SCB design guidelines and criteria
Humidity (dew point)	4.4° to 15.6° (40° to 60°F)	SCB design guidelines and criteria
Guidance and navigation		
Stability	± 0.1 deg	Phase-B analysis
Rate stability	0.05° deg/sec (short term)	
Pointing accuracy	± 0.05 deg	
Position accuracy	± 0.5 km (altitude)	
Power		
Bus voltage/freq (VDC)	$28 \begin{smallmatrix} +3 \\ -2 \end{smallmatrix}$	Standard equipment requirements

Requirement	Level	Source
Bus voltage/freq (VAC)	110 $^{+10}_{-5}$/400 ± 10 Hz	
Crew		
Shifts/day	2	SCB crew productivity analysis
Hours/shift	10	SCB crew productivity analysis
EVA duration	6 hr/day/crewman	Orbiter suit limitation
EVA crewman	2/shift	SCB construction/safety
SCB/EVA	2	Number of crew EVA req'd for construction objective element analysis
Communications		
Voice channels (300 to 4,000 kHz)		
Intercom	2	Min operational, min backup
SCB/grnd (relay)	TBD (32 kbps)	Conforms to STDN format requirements
SCB/grnd (direct)	1 (32 Kbps)	Min backup capability
SCB/Orbiter	2 (32 Kbps)	Min operational, min backup
SCB/free-flying vehicle	2 (32 Kbps)	Min operational, min backup
SCB paging	N/A	Override capability all channels
Video channels (4.5 MHZ)		
SCB/grnd (relay-downlink)	2	Analysis of min simultaneous transfer requirements
SCB/grnd (relay-uplink)	1	Min reqm'ts for video transfer (technical and entertainment

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Digital channels		
SCB/grnd (direct-downlink)	TBD	Subsystem data transfer
SCB/grnd (direct-uplink)	TBD	Command/data transfer
SCB/grnd (relay-downlink)	TBD	Status/operations data transfer
SCB/grnd (relay-uplink)	TBD	Operations, program data transfer
SCB/free-flying veh (command)	TBD	Vehicle control, ranging
SCB/free-flying veh (response)	TBD	Status, ranging data transfer
SCB/Orbiter (to)	TBD	Status, ranging data transfer
SCB/Orbiter (from)	TBD	Status, ranging data transfer
Closed-circuit TV channels	TBD	Crane operations, SCB surveillance
Data management		
Processing rate (EAPS)	TBD	Subsystem control
Operating memory (words)	TBD	Operating program storage
Main memory (words)	TBD	Rapid access program storage
Archive memory (words)	TBD	Data bank storage
Data transfer rate (Kbps)	TBD	Serial data transfer requirement
Data transfer bandwidth (Hz)	TBD	Analog/video transfer requirement

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Mission support equipment		
EVA work station		
Capacity	2 crewmen	Operations analysis
Work area	2.5x1.5x1.5m (8.2x5x5 ft)	
Illumination	202 lumen/m^2 (20 ft-candles)	Lighting requirements analysis
Control center		
Closed-circuit TV monitors	8	TA-1 analysis
Antenna pointing/steering monitor and display	N/A	
Command transmitter (BMS)	N/A	
Display - BMS position and rate	N/A	
Computer processor	N/A	
Film developer and reader equipment	N/A	
Beam mapping satellite		
Range radar	N/A	TA-1 analysis
Boresight camera	N/A	
Tracking camera	N/A	
Berthing ports	4	TA-1 analysis
Pressurized workshop volume	20 m^3 (706 ft^3)	TA-1 analysis
3 Man airlock volume	10 m^3 (353 ft^3)	TA-1 analysis
Subsatellite		
Launcher control		Antenna test requirements analysis

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Console		
Size	TBD	
Volume	0.01 m^3 (0.35 ft^3)	
Mass	12 kg (26 lb)	
Electrical power	TBD	
Signal interface	TBD	
Subsatellite launcher		Antenna assembly anslysis
Size	TBD	
Volume	TBD	
Mass	250 kg	
Electrical power	TBD	
Construction Support Equipment		
Mobile crane		TA-1 construction analysis
Mass handling capacity	14.5 kg (32,000 lb)	
Number arms	2	
Reach	35m	
Degree of freedom	7	
Programmable envelope (collison avoidance)	Yes	
End effector position error	40 mm any axis	
End effector attitude error	3 degrees any axis	
Mobility	Not required	
TV viewing imaging	Zoom 10:1	
TV viewing aperture	Automatic	

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Control console size	0.2 m^3	
Control console mass	60 kg	
Tip force	9 Kgf (20 lbf)	
Construction fixture frame (solar array)		TA-1 Construction analysis
Size	1x12x33.5m	
Mass		
Natural frequency	TBD Hz min	
Bending stiffness	TBD	
Lighting - exterior	Yes	
Lighting - interior	No	
Pressurization	No	
Robots	Yes	
Beam Cap Machine		TA-1 Construction analysis
Size	2m dia x 7.5m long	
Mass	TBD	
Number	6	
Pressurization	No	
Electrical power	TBD	
Construction fixture (antenna)		TA-1 Construction analysis
Volume (including extended tubes)	664 m^3 (23,430 ft^3)	
Mass		
Natural frequency	TBD	

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Bending stiffness	TBD	
Lighting	Yes	
Pressurization	No	
Robots	Yes	
Composite-tube fabrication module		TA-1 Construction analysis
Volume	12m x 4.06m dia (39 ft x 13.3 ft dia)	
Indexing turntable		
Size	2.2m dia x 0.6m (7.2 ft dia x 2 ft)	Antenna assembly analysis
Rotation	$\pm 360^{\circ}$	
Indexing	Yes	
Mass	230 kg (506 lb)	
Min MOI capability	TBD $kg\text{-}m^2$	
Mass capacity	16,000 kg (35.2 klb)	
Control console size	TBD m^3	
Control console mass	TBD kg	TBD
Assembly beam		Antenna assembly analysis
Size - minimum	16m length (52.5 ft)	
Mass	560 kg (1.2 klb)	
Natural frequency	TBD Hz minimum	
Test equipment		
Beam mapping satellite		TA-1 analysis
Size	2m dia x 2M (6.6 ft dia x 6.6 ft)	
Mass	<1,000 kg (<2.2 klb)	

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Volume	TBD	
Emission bandwidth	TBD	
Range	3.4 km (1.8 nmi)	
Operating life	TBD	
Propulsion capability	500m/sec (1.6 Kft/sec)	
Test, calibration, and checkout equipment		TA-1 analysis
Size	TBD	
Mass	TBD	
Volume	TBD	
Electrical power	TBD	
Beam mapping satellite-C		TA-1 analysis
Size	TBDxTBDx360m (TBDxTBDx1.2 Kft)	
Mass	TBD	
Volume	TBD	
Emission bandwidth	TBD	
Range	3.4 km	
Operating life	TBD	
Rectenna size	15m x 20m (50 ft x 66 ft)	
Subsatellite		Antenna test requirements
Size	TBD	
Mass	TBD	
Emission bandwidth		
Range	185 km (100 nmi)	

OPTION L (PERMANENTLY MANNED) REQUIREMENTS - Continued

Requirement	Level	Source
Volume	1.66 m^3 (58 ft^3)	
Capacity life	TBD hrs	
Test, calibration, c/o equipment		Antenna test requirements
Size	TBD	
Volume	3.0 m^3 (105 ft^3)	
Mass	100 kg (202 lb)	
Quantity	TBD	
Electrical power	TBD	
Subsatellite control console		Antenna test requirements
Size	TBD	
Volume	0.135 m^3 (4.7 ft^3)	
Mass	45 kg (99 lb)	
Electrical power	TBD	
Signal interfaces	TBD	
Radiometer control console		Antenna test requirements
Size	TBD	
Volume	1.2 m^3 (42 ft^3)	
Mass	200 kg (440 lb)	
Electrical power	TBD	
Signal interfaces	TBD	
Logistics		
Transport		
Mass	500,000 kg (1.1M lb)	Transport requirements analysis (16 years)

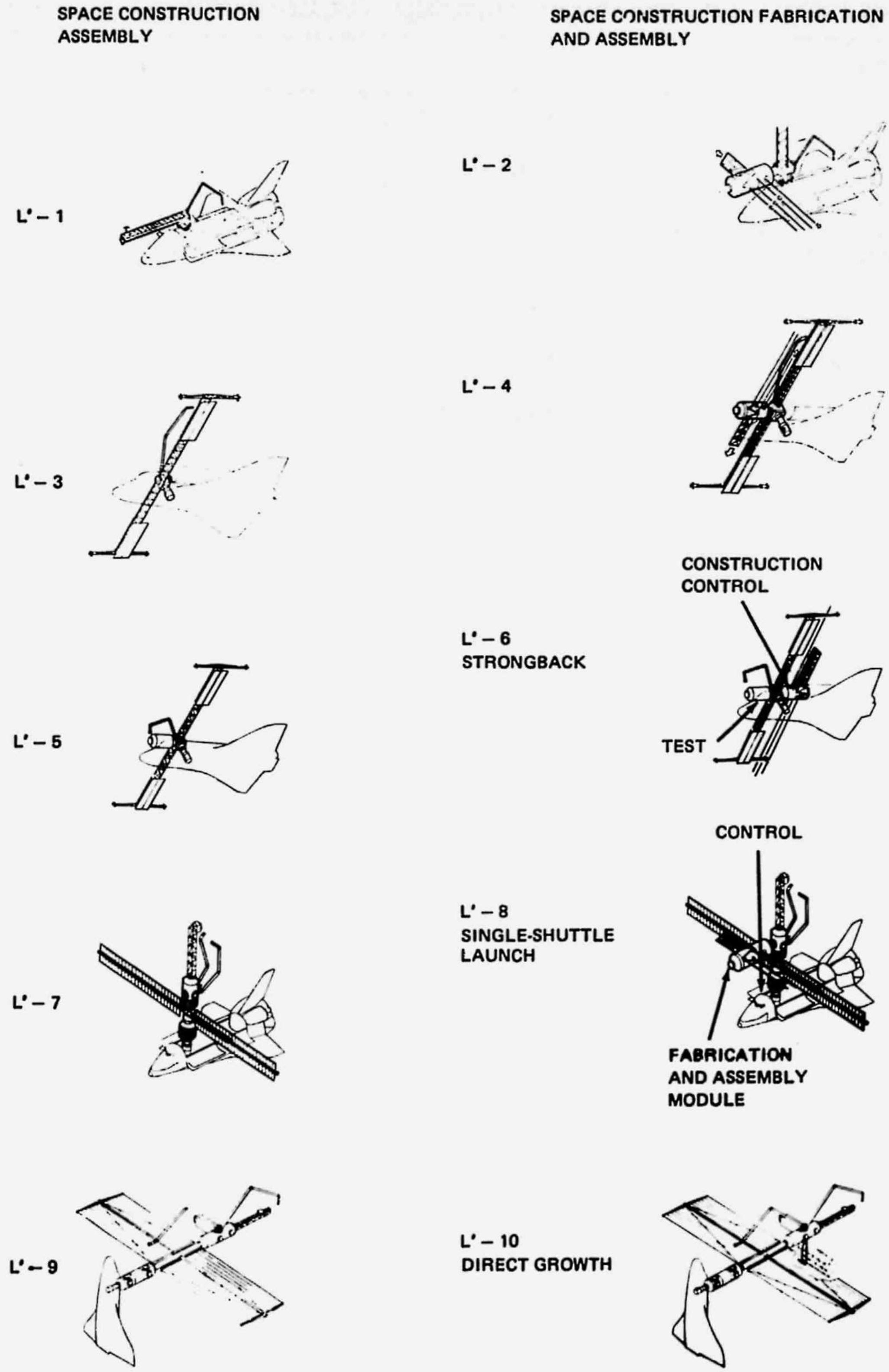

Figure 5-14. SCB Systems L' Options (Shuttle-Tended)

of both fabrication and assembly operations. L'-1 represents the most fundamental configuration, possessing an RMS crane, an extendable 15.5m-long assembly beam with an indexing turntable at its end. L'-2 uses the same extendable beam, but also possesses a truss fabrication and assembly module to fabricate small tubes and provide an assembly jig to make trusses. L'-3 and L'-4 are variations of the simpler configuration. L'-5 and L'-6 represent the strongback use with small fixed solar arrays at each end and a test and construction control module attached. The L'-9 and L'-10 options represent further increased capability and have the inherent flexibility of direct growth to a permanently manned SCB.

The permanently manned program Option L, with logistics and crew rotation performed by the Shuttle, provides sufficient docking and berthing ports, pressurized habitation and control facilities, power, and heat rejection capabilities sufficient to support all phases of the program. The SCB configuration for Option L is capable of autonomous operation during both manned and unmanned periods. The initial space construction which originates from the SCB may range from EVA-manual assembly to automated fabrication and assembly. Fabrication will most likely be only partially automated at the outset. As operations mature and construction sizes and schedule durations dictate, the SCB should allow more fully automated assembly support equipment to be phased into the program.

By the addition of modules that provide the capacity for unattended manned operations of appreciable duration, the L' SCB can be developed into a large-scale, permanently manned facility. The nucleus L' facility consists of a strongback structure and an attached control module. The growth facility is developed by the addition of modules along the original Orbiter docking axis.

First, a space construction support module is added to the strongback structure. This module includes berthing ports for four additional modules or construction tools, one of which is an advanced mobile crane having a reach in excess of 30m. The support module also includes a 4-man EVA airlock (exiting through a side port) in which all the EVA support equipment is contained.

Next, an electrical power system module is added with a solar array sized to totally support the orbital facility construction and test operations. This is followed by the addition of a core module to which the habitation, the space processing and logistics modules are berthed. The longitudinal axis of this core module also provides a docking port for the Shuttle vehicles.

The original strongback truss beams may have structure added to provide the basis for a construction tool for the TA-2 objective element. After the strongback is built into an appropriate framework, longeron fabricating modules, rolls of array surface materials, automated robots, and other equipment complete the fixture, and the construction of TA-2 can begin.

The basic 7-man SCB configuration (Figure 5-15) has the capability of supporting both fabrication and assembly of object element mission hardware plus commercial space processing activities. The single power module supplies power up to 34 kW to supply the demands of the SCB. The basic elements of the SCB, in addition to the habitation elements, include the fabrication and assembly facility. This facility consists of the space construction support module, mobile crane, composite tube fabrication module, universal truss

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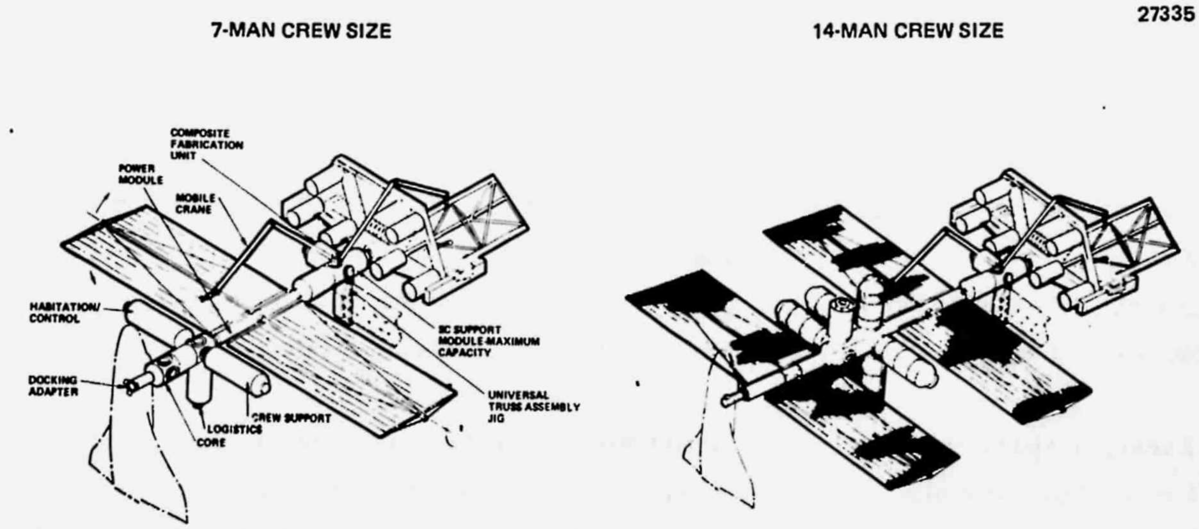

- FABRICATION AND ASSEMBLY
- SPACE PROCESSING
- MDL
- SENSOR DEV AND TEST
- LIVING AND WORKING IN SPACE

Figure 5-15. Program Option L, Permanently Manned

assembly jig, and solar collector fabrication and assembly jig. Following deployment of the fabrication and assembly facility tooling, the objective elements can be installed. The 14-man configuration shown in the figure is a direct growth version of the 7-man station.

SCB growth in capability and size with time is illustrated in Figure 5-15 by the 14-man configuration. In this operational mode, several objectives can be simultaneously conducted with the subsequent increase in power requirements. As the power level reaches 60 to 70 kW, it will be necessary to add a second power module. In addition to the aforementioned fabrication and assembly capabilities and space processing, the 14-man configuration can add a multiple disciplinary science laboratory and a sensor development facility, and provide living and working in space experiments.

5.3.1 Program Option Requirements Analysis

Requirements for the fabrication and assembly facility are predicated on the ability to provide a versatile general construction base. In particular, the facility must provide the fabrication and assembly elements to construct SPS TA-1, TA-2, and the 30m toroidal radiometer. In the case of these three objective elements, the machine required to fabricate the tubular components for TA-1 should also be capable of fabricating the composites for the cross-beam truss in TA-2 and the composites used for the antenna support structure for the 30m radiometer. Similarly, the assembly fixtures for TA-1 should also be used for the construction of the TA-2 antenna and the 30m radiometer.

Analysis of TA-1 and TA-2 construction requirements revealed that significant EVA effort is required with a supporting crane. This crane must be able to hold parts for cut, trim, and joining operations. At each EVA work station, a significant complement of tools, services, restraints, force/torque reaction capability, etc., is needed. It is clear that the required capability is beyond what can be conveniently carried by the EVA crewman. Separate, semicontained quarters at each EVA work station are needed. This support should be adequate for two EVA crewmen.

Typical activities which require space construction support include fabrication, subsystem integration, and checkout and testing of components and subassemblies. Assembly requirements are associated primarily with handling.

Materials include aluminum or composite tubing, panels, waveguides, electrical and mechanical components, and cables. The elements range in mass up to 3,000 kg. These elements may be as small as $0.01m^3$ or as large as $250\ m^3$. Crane capabilities should allow translation of the larger masses a distance of at least 15m.

A variety of joining techniques must be considered for possible SCB applications. These include fasteners such as rivets, eyelets, and staples, and other means such as crimping, bonding, and bolting. Fabrication operations also include requirements for automatic beam forming equipment for aluminum channels and composite tubing for the objective element mission hardware and related assembly fixtures. Checkout and integration of the subsystems is performed by the SCB as well as an "all systems test" after completion of an objective element.

The crew sizes necessary to construct and test the TA-1 antenna and the TA-2 solar array range from one to three individuals. The average and peak electrical power requirements for objective elements TA-1 and TA-2 necessitate an average of 9 kWe for the construction of TA-2 and a peak of 80 kWe at 20,000V from the SCB power source to satisfy the TA-1 test requirements. Temporary storage volumes of approximately $200m^3$, external to the SCB, are needed for parts unloaded from the Shuttle during construction. These volumes are in addition to berthing and storage requirements for TA-1 and TA-2 tooling fixtures, and temporary storage of 3-10m beams, 30m long (TA-2 cross braces).

The TA-2 solar array should be oriented away from the sun during construction to minimize danger from high voltages. The antenna performance of TA-1 and TA-2 is evaluated in conjunction with the beam-mapping satellites in the same orbit as the SCB; consequently, the antennas must be pointed approximately along the SCB velocity vector during test operations.

Alignment checking devices will be required for the beam-forming units and for the antenna subsystems.

This study has taken full advantage of the Phase-B Space Station (NAR) functional requirements and the module concept approach which was used.

There is a high level of commonality. A primary difference is the added length (15.2m), which still permits the usage of DMS, docking adapters, and tunnels. Functional requirements for the power module are the same with the primary difference in the physical features being the larger soiar array necessary.

High power requirements exist for both the space development of the production processes for ultrapure glasses and shaped crystals. For example, the ultrapure glass processing requires an average electrical power of 20 kW and a peak power of 30 kW. Appropriate operational scheduling of these objective elements in Program Option L will be required to maintain total bus power at a level compatible with a single power module (i.e., an approximate 35 kW at end of life).

5.3.2 Orbiter Constraints

Orbiter constraints have a significant impact on the dimensional definition of the SCB module. The maximum allowable payload in the Orbiter cargo bay, and the location of envelope of these limits within the Orbiter, is shown in Figure 5-16A. The envelope described is of cylindrical shape with a diameter of 4.57m (15 ft) around a centerline parallel to the Orbiter X_o axis at Orbiter stations Y_o = 0 and Z_o = 400 (10.16m). The length of the envelope is 18.28m (60 ft) extending from station X_o = 582 (14.78m) to station X_o = 1302 (33.07m). A 3-in static clearance is required between the payload dynamic envelope and Orbiter structure and equipment. This clearance permits the Orbiter structure and equipment to deflect (thermally and structurally) without physical interference with the payload. A maximum payload static envelope of 174 in (4.42m) diameter and a maximum length of 18.28m (60 ft) has been selected as baseline for all candidate payloads.

Module lengths are mission dependent. Figure 5-16 also illustrates the various combinations as they relate to the auxiliary equipment necessary to perform various mission objectives. In each case, full use of the cargo bay is accomplished except when the Orbiter docking module is incorporated for missions requiring direct docking to transfer payloads from Orbiter to the SCB.

Clearances defined in Figure 5-16E limit the length of payload modules to 14.5m (47.58 ft). The maximum external dimension of the module is 4.42m (14.5 ft) diameter and 14.50m (47.58 ft) in length. Mechanisms that are external but

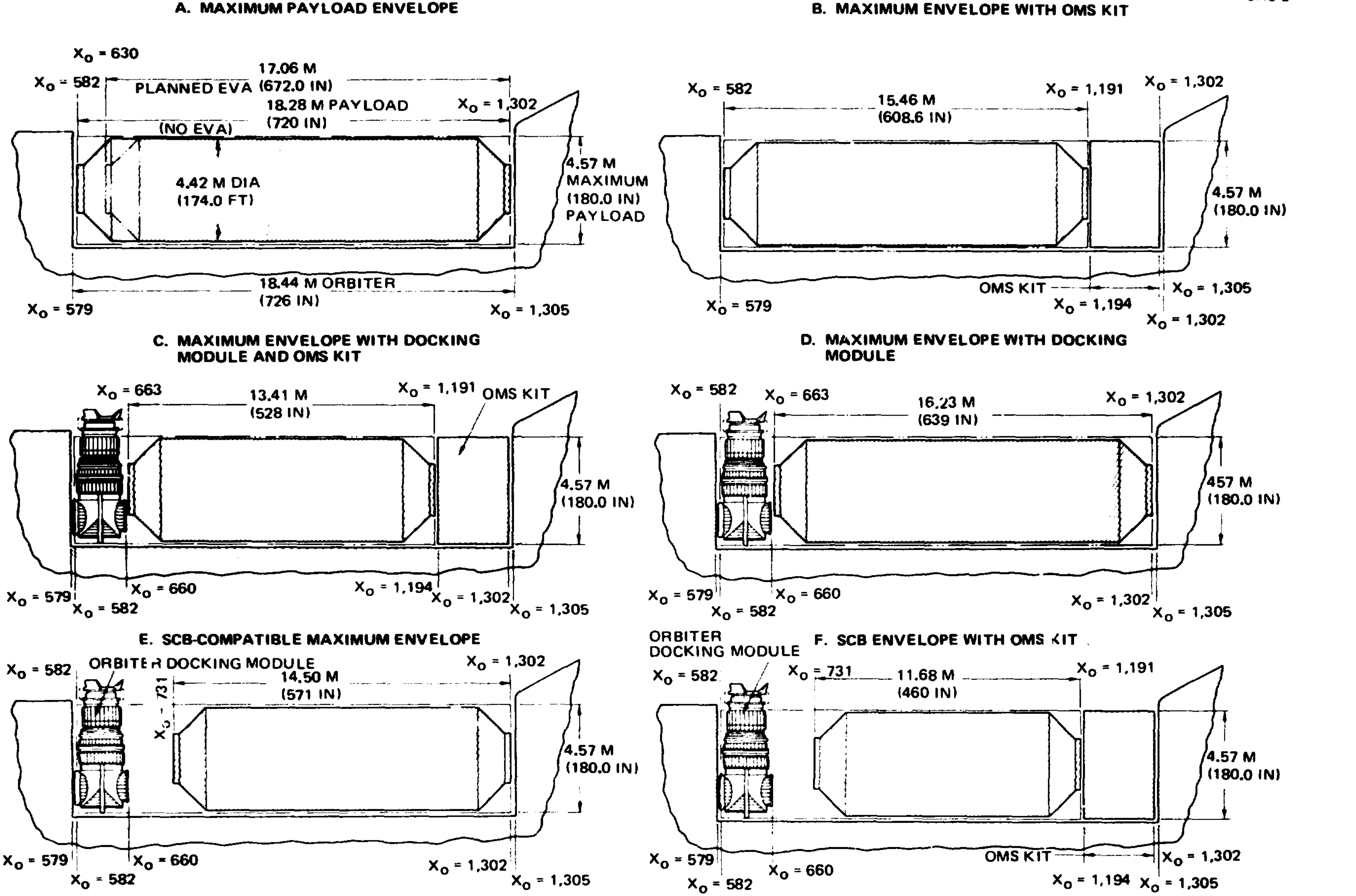

Figure 5-16. Payload Envelope Configurations

are attached to the module, such as Orbiter attach fittings, deployment attachments, docking and berthing mechanisms, thrusters, etc., are contained during launch within the defined dynamic envelope. The only exceptions are the structural interface attach fittings.

Deployment of payload modules from the Orbiter cargo bay is accomplished by the payload installation and deployment aid (PIDA), which rotates the payload from the interior of the Orbiter bay to an external position at $Y_o = 171.7$ and $Z_o = 544.7$. After the PIDA has been secured in the deployed position, the payload may be removed by using the Orbiter RMS or the SCB mobile crane. A clearance of 0.5m was selected as the minimum distance to avoid impact damage to the payloads and the SCB. To avoid contact with SCB modules berthed to the core module, a minimum distance of 8.5m (27.8 ft) is required between the Orbiter and (Z_o - 400) and the SCB module. This clearance is assured with incorporation of an interface adapter 2.1m (6.8 ft) in length. The adapter would be configured to interface with the berthing port on the SCB core module and the international docking adapter on the Orbiter docking module. Limiting the payload dimensional envelope and incorporating the interface adapter enables the Orbiter to dock with the SCB, on the X axis, without positioning limitations.

5.3.3 SCB Module Definition

The SCB module definitions were derived using the design requirements from the NAR Phase B Space Station Study. To maximize Orbiter performance and reduce the number of modules, with inherent cost savings, a consolidation of the Phase B design requirement was undertaken.

The orbiter delivery and rendezvous cargo weight capability for the selected 55 degree inclination and 400 km (215 nmi) altitude yielded more cargo performance than was available with the volume and lateral center of gravity constraints. Using parametric weights with a plus or minus 25% margin developed from prior studies and hardware controls, the weights were overlaid on the Orbiter lateral center of gravity. From this projection, as illustrated in Figure 5-17, the maximum mass is 15,400 kg (33,950 lbm) at a length of 15.3m (50 ft). The cg excursion can be varied 5% to 10% by selective mass distribution and the excursion is not a limiting factor. The 15.3m length is considered

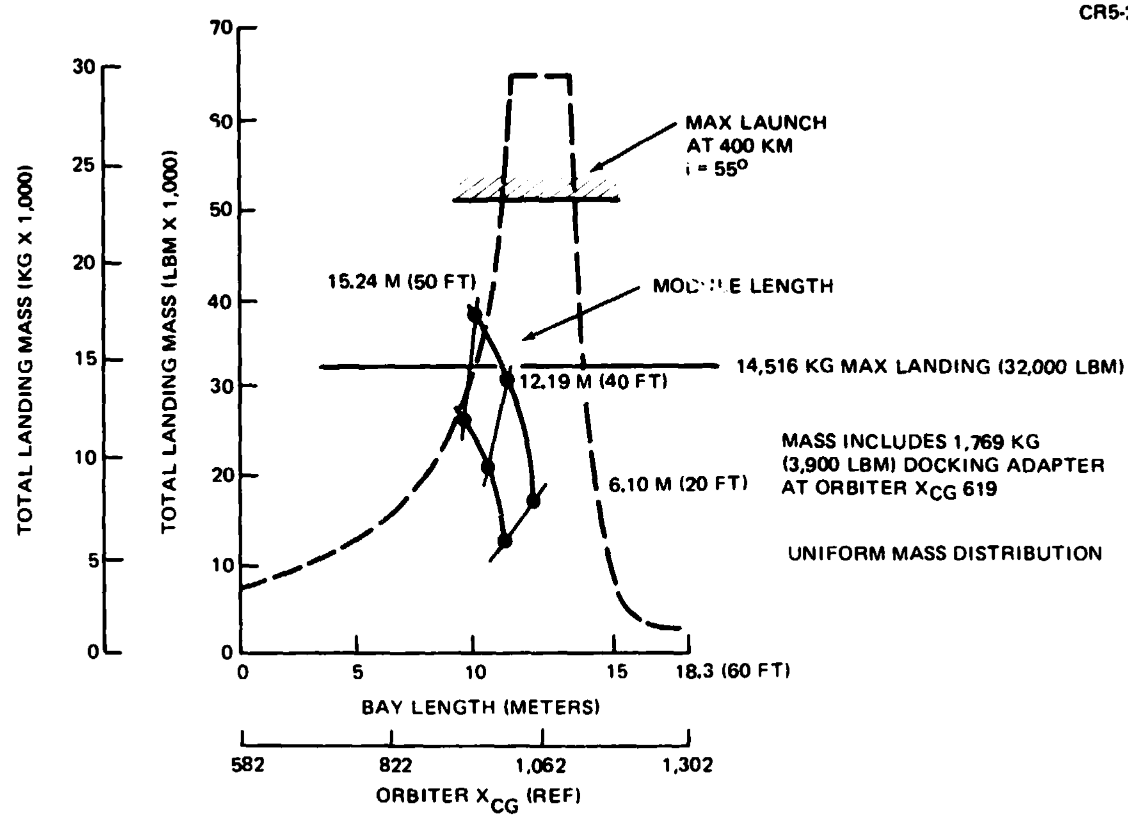

Figure 5-17. Module Landing Mass Versus Orbiter Lateral CG with Docking Adaptor

maximum to not preclude use of OMS, the docking modules, and erection out of the bay of the modules.

With sufficient cargo margin at maximum length and diameter of 4.41m (14.5 ft), a 32% increase in module volume was obtainable. A review of the functional volume allocations commensurable with the increased volume and mass capability permitted the removal of two Phase B support modules. This gross volume comparison is illustrated in Table 5-8 with a 15% margin for the extended-length SCB option. The Phase B module had approximately 215 m^3 (7,600 ft^3) of experiment activities and related support volume allocations. Individual module allocations are summarized in Table 5-9. The addition of a seventh crewman was more than offset by the distribution as noted; the resulting volume change was a reduction of 25 m^3 (900 ft^3). This is 3% more volume than the Phase B for the crew/habitation modules. A further margin is available with a review of the original functional volume requirements as the Phase B study had excess margins capability of approximately 59 m^3 (2, 100 ft^3) for the four referenced modules.

Table 5-8
VOLUME COMPARISONS

Modules	Phase B	SCB
*Crew/Habitation	671	445
Space Construction	-	221
Subtotal (m^3)	671	666
Core	110	218
Power	34	54
Total (m^3)	815	938

*Experiments and Related Support volume 215 m^3

The resulting power module functional requirements are the same with the primary difference in physical features being the larger solar array, which dedicated a longer boom mounted at mid-length. An advantage to the extended length is the ability to berth directly to either end. A second-order advantage is the increased volume.

The core module functional requirements are the same as for Phase B except for the addition of 180 hr of emergency ECLS pallet (personnel rescue system provisions), and consolidation of the EPS electrolysis. In the extended SCB concept, a common diameter (4.4m) was selected for the radial modules, the reduced diameter (2.9m) concept of Phase B being volume limited.

The control/habitation module is similar to the Phase B SM-1. The primary difference is that all crew stations and hygiene are located in this module plus the air revitalization and a second 180-hr emergency ECLS pallet. Consolidation of direct crews support functions permits growth to a 14- or 21-man SCB with the addition of similar modules. Growth is also the reason for location of the second thermal control system in this module rather than in the crew support module.

The crew support module is primarily a consolidation of functional requirements of the Phase B SM-3 and -4. The exceptions are the backup control center which was allocated to the space construction module along with the hygiene support. The thermal control was placed in the core module because a emergency system already existed there.

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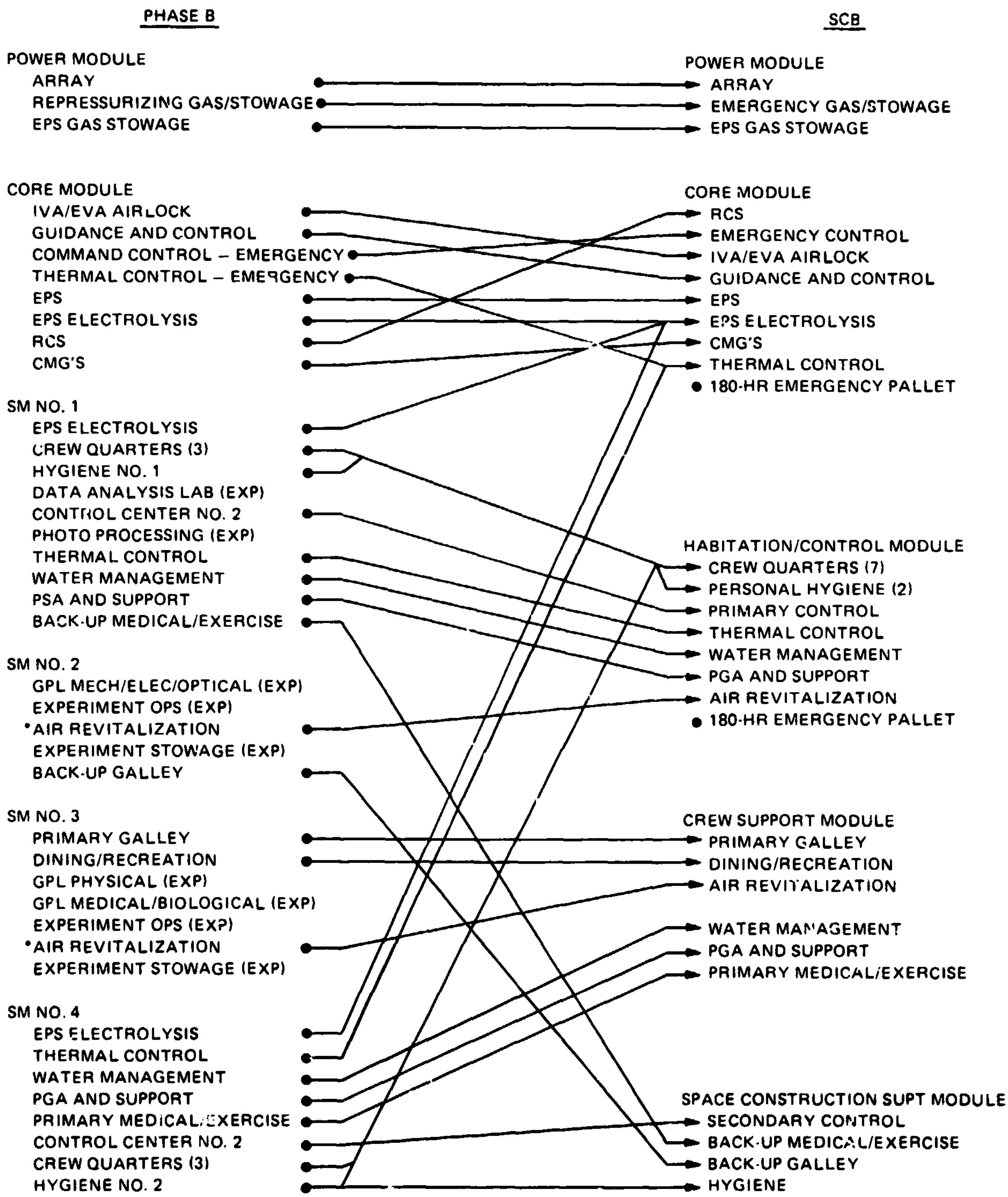
Table 5-9. FUNCTIONAL REQUIREMENT ALLOCATIONS



*H_2O ELECTROLYSIS

The SCB houses the support requirements for fabrication and assembly support. The backup control center and medical, exercise, galley, and hygiene facilities are located here because of EVA activities and distances from the primary crew/habitation support functions.

Table 5-10 incorporated these results into a mass summary. Using 400 km as the orbital altitude, a cargo mass of 24,040 kg (53,000 lbm) is available for delivery and 22,680 kg (50,000 lbm) for rendezvous. In all cases, a margin of 50% plus is available.

Table 5-10
SCB MODULE MASS SUMMARY

Module	Mass kg	Mass (lbm)
Core	15,300	(33,730)
Power	12,800	(28,220)
Control/Habitation	13,300	(29,320)
Crew Support	13,200	(29,100)
Space Construction	14,520	(32,010)

5.3.4 Shuttle-Tended Phases for SCF

In the study of potential avenues to a permanently manned SCB, a family of Shuttle-tended concepts has been derived. All concepts have the same capability in the sense that they will support the construction of the same kinds of objective elements; however, they vary as to sophistication or capacity of equipment with consequent impact on labor achievement rates and, therefore, the number of launches and overall duration in a given program option. To a large extent, the varying levels of equipment complexity would also result in varying levels of initial funding.

The Shuttle-tended concepts are an initial phase and the descriptions of necessary equipment additions, deletions or alterations for growth to the independent permanently manned facility are also presented. These Shuttle-tended concepts include three types of configurations: direct growth, single launch, and what is referred to as the strongback concepts. The crew sizes

related to these configurations vary from four for strongback concepts to seven for direct growth concepts.

The method of developing the Shuttle-tended configuration concepts is similar to that used for the all-up SCB concepts. In general, those items shown in Figure 5-18 for standard modules are assigned to the Orbiter, while those items assigned to fabrication and assembly facilities are retained for the dedicated equipment.

The primary configuration drivers for the Shuttle-tended concepts (L') are essentially the same as for the SCB (L) except to a smaller or less ambitious scope and include:

- Objective element support requirements.
- Space construction techniques.
- Material-handling techniques.
- Subsystem type.
- Growth methods.

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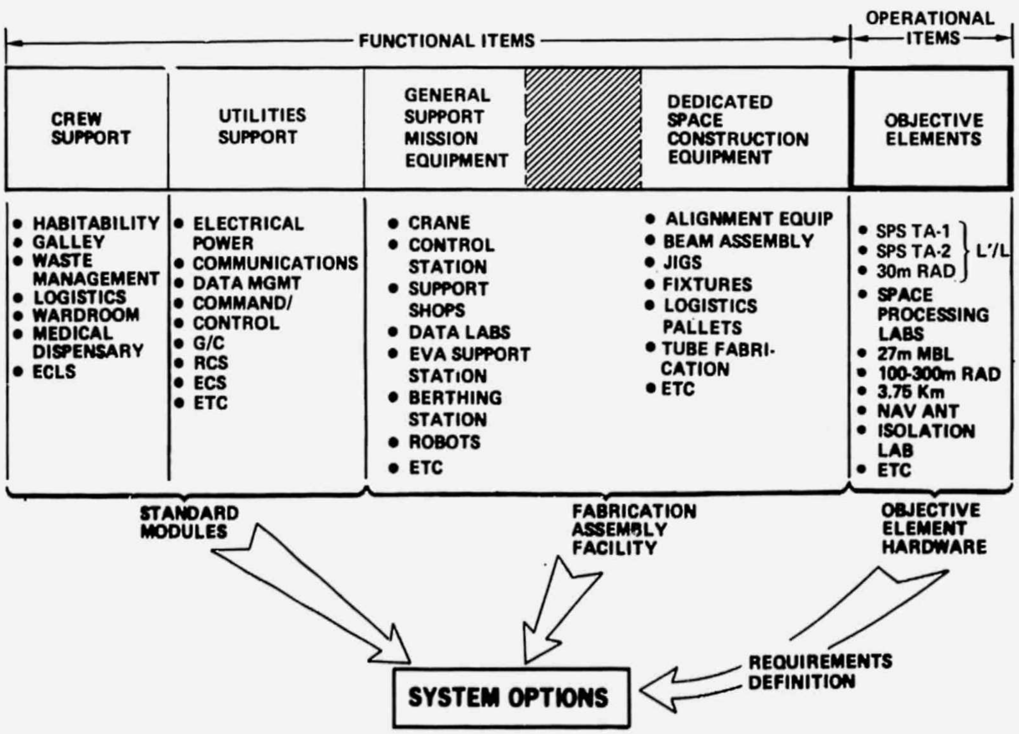

Figure 5-18. Space Construction Base Definition — Permanently Manned, Option L

The penalties in construction achievement rates which result from the limitations of the Shuttle-tended mode is readily apparent when examined whether from single-shift operations, serial instead of parallel operations, and physical constraints of equipment (reach envelopes, manual techniques, force limits, etc.).

The objective element support requirements are (as with L program options) oriented to space construction and space processing. As a preliminary phase of the SCB, the objective elements considered were limited to the construction of the 30m parabolic toroid radiometer, the SPS Test Article 1 (TA-1) and sortie-type space processing. For the capabilities of the Shuttle-tended mode, the design of the objective elements may require consideration of reduced handling capability and a greater degree of prefabrication. The designs may require more integral mechanical joining aids and devices than for a more advanced facility. Space processing may require full automation (except for startup and periodic monitoring) and a suitcase concept during assembly periods for large structures, but may involve a man during radiometer or TA-1 test periods. Many elements of support equipment in the Shuttle-tended concepts will operate on a sortie basis and time phasing must be studied in depth to properly structure the mission profiles.

The principal construction techniques considered for the Shuttle-tended mode include those considered for the SCB (L) program options:

- Deployable.
- Manual assembly.
- Automatic assembly.
- Orbital fabrication with manual assembly.
- Orbital fabrication with automatic assembly.

The tended (L') concepts logically address two basic approaches: prefabrication and assembly and on-orbit prefabrication and assembly. Limited automation may be considered as consistent with the Shuttle-tended philosophy but is reserved for TA-1 construction only. The automation might appear in only two places, namely, in the tube fabrication process (which might be a pultrusion process) or a robot arm used in placing struts on the TA-1 antenna beam assembly.

Requirements for growth compatibility were initially omitted so as not to constrain the configuration concepts. However, after a practical family of concepts evolved they were iterated to improve their growth potential. This was generally done through the selection or placement of berthing ports, EVA and pressurization considerations, gross facility orientations, and some subsystem placement.

With the approaches and considerations above, a limited number of L'oriented groundrules were identified to supplement the groundrules applicable to the SCB. These are listed in Table 5-11.

Table 5-11.

SCB CONFIGURATION OPTIONS (L')
Shuttle-Tended

General Groundrules

- Shuttle-tended operations — SCB remains on orbit
- Provide capability consistent with requirements at each phase of program option
- Utilize 07700 Orbiter definition with 30-day kits
- Unmanned SCB subsystems may be semi-autonomous and/or fully replaceable
- Construction may range from EVA-manual assembly or fabrication/ automated assembly.

Operational Groundrules

- Orbiters maximum docked/support duration - 30 days
- Crew will use Orbiter for hatibation/support
- 7 m^3/man of free space in Orbiter is operational goal
- Allowance for 90-days of SCB free-flight consumables during undocked periods
- Crews will operate on:
  - One-shift basis when living and working from Orbiter
  - Two-shift basis when space construction support module/space processing module is available
- Fabrication/assembly and test operations will be sequential.

A preliminary configuration analysis to determine what functions and capabilities should exist and where should they appear for various degrees of Shuttle dependency was done. Table 5-12 shows these assumptions which are the basis of structuring for the family of L' configuration concepts which follow.

Table 5-12

SCB (L') SYSTEMS OPTIONS
Orbiter Support Levels

Support Area/Subsystem	Maximum Dependence		Nominal Dependence		Minimum Dependence	
	Manned	Unmanned	Manned	Unmanned	Manned	Unmanned
Habitability/crew support	0	-	0	-	0	-
Electrical power	0	S	0/S	S	S	S
Environmental control/life support	0	-	0	-	0/S	-
Thermal control	0	-	0/S	S	0/S	S
Stabilization/control	0	S	0	S	S	S
Reaction control	0	S	0	S	S	S
Communications	0	S	0	S	0	S
Command/control	-	S	-	S	-	S
Data management	0	-	0	-	0/S	-
EVA airlock	0	-	S	-	S	-
EVA airlock support	-	-	-	-	S	-
Stationkeeping	0	-	0	-	0	S

0 - Orbiter (Docked)

S - SCB

5.3.4.1 Single-Beam Strongback (L'_1 and L'_2)

The simplest hardware configuration defined has the greatest degree of Shuttle dependency. It relies almost entirely on Shuttle provisions and accommodations except for the mechanical support of the objective element under construction. All crew activity except direct EVA participation in the assembly process is contained within the Orbiter.

The orbital facility consists basically of a simple truss-work strongback on which to assemble the objective element. Limited subsystems and assembly aids are mounted on the beam strongback. An orbiter RMS is mounted on a turntable to provide a manipulator reach which includes much of the cargo bay of the Orbiter and much of the assembly activity zone of the objective element. The effective reach envelope is partially expanded by hinging the strongback at its middle fold point.

The primary element of the strongback consists of a hinged, folded truss beam attached to a core structure. The free end of the strongback beam has a ring structure attached which, through its members and bearings, provides a turntable mounting base for the objective elements. That is, during the buildup of an objective element, it can be rotated to provide the best zone of access and observation between the assembly operations and the RMS or EVA support and control center. The free end of the beam also mounts portions of some subsystems such as propulsion ACS modules, antennas, lights, and EVA suit services and may contain stowage lockers for assembly tools or aids. To provide the highest possible stiffness in the beam structure to minimize dynamic flexure between the objective element and the docked Orbiter, the beam would most likely be composed of composite material tube elements (i.e., graphite-epoxy).

The strongback beam is attached to a core structure which also supports and provides the interfaces between the various logistics modules which are berthed on the facility and the Orbiter itself. The core structure consists of a box truss which contains a semimonocoque tunnel, attach fittings for the strongback beam, two lateral berthing ports, and support structure for various subsystems.

The tunnel provides EVA passage from the Orbiter docking module and airlock to free space outside the facility. One end of the tunnel has a rotatable ring structure on which an Orbiter RMS is mounted. The RMS is hardwired to its Orbiter interface which constrains the rotational envelope to ± limits from a nominal position. This lack of unrestricted rotation should not burden the assembly operations if the rotation limit is large (at least ±270 deg to ±350 deg). The RMS may be controlled from one of two locations. The first is the Orbiter RMS control station, and the second is a control console on the RMS rotating base. For this level of facility concept, the first preference would be to use the Orbiter control station; however, direct vision from the Orbiter, whether for cargo bay operations or objective element operations, is limited if not useless. The docking module, while in the docked mode, precludes viewing the bay while the strongback and other equipment obstruct the view of the assembly zone. Television viewing would be the only practical control method for Orbiter control station operations. A more complex approach is to mount a control console on the RMS rotating base where an EVA control crewman would have direct vision of virtually all RMS operations.

The other end of the tunnel has a docking system which is compatible with the Orbiter and provides pigtail cables to be interfaced with the appropriate Orbiter cabin feedthrough panels for hardwire and other functions to the facility. Should the strongback have a place in the growth to an all-up independent permanently manned SCB, the docking system should be removable to provide an interface with the SCB modules.

The berthing ports on the sides of the core structure are configured to receive logistics modules which variously contain prefab parts or materials for the objective elements, momentum wheels for better than Orbiter stabilization during tests, electrical power systems for support of testing, and for the L'_2 option, a minibeam assembly module with tube fabrication capability.

The primary subsystems which are included on the strongback as facility systems are to be engineered to provide functional service during the facilities

free-flying mode during Shuttle rotation. Nominally, the free-flying period would be short with one Orbiter standing by to dock while the other debarks for return. The systems should, however, be sized to provide facility control or at least control recovery (after a passive coast phase) when considering either single Shuttle programs or aborted launch schedule impacts where the coast phase may be approximately 16 days. Added margin consideration may then produce capacity cycle requirements of approximately 90 days. The subsystems considered consistent with the fundamental technology level of this concept include ACS propulsion modules consisting of several integrated thrust and tankage modules, electrical power via ground-charged battery packs, and Orbiter or other off-the-shelf electronic communications and guidance (attitude) components. These subsystem components would be appropriately located and installed in a strapdown mode to facilitate easy logistics replacement servicing.

The $L'_{1,2}$ concept is the only one of the family presented which, at least at this time, cannot be said to provide a beneficial part in the buildup to the permanently manned SCB. The structures which make up this facility would be returned to earth and the SCB (L) would develop entirely on its own hardware.

5.3.4.2 Double Strongback (L'_3 and L'_4)

The double strongback concept carries the preceding concept one step further, providing dual beams with two objective element turntables (Figure 5-19). This concept is also extensively Orbiter oriented with all crew activities within the Orbiter except for direct EVA activities. The descriptions of the various elements are essentially the same as for the single-beam strongback.

The strongback beams are similar in size, construction, and material to $L'_{1,2}$ except that, instead of folding at midpoint, the two segments are step-sized to telescope. The outer segment lengthwise is also the outer segment cross-sectionally. Thus, subsystems can be mounted on the outer segment and end up at the deployed extremities of the beams.

The core structure is also virtually identical to $L'_{1,2}$ except for supporting two strongback beams.

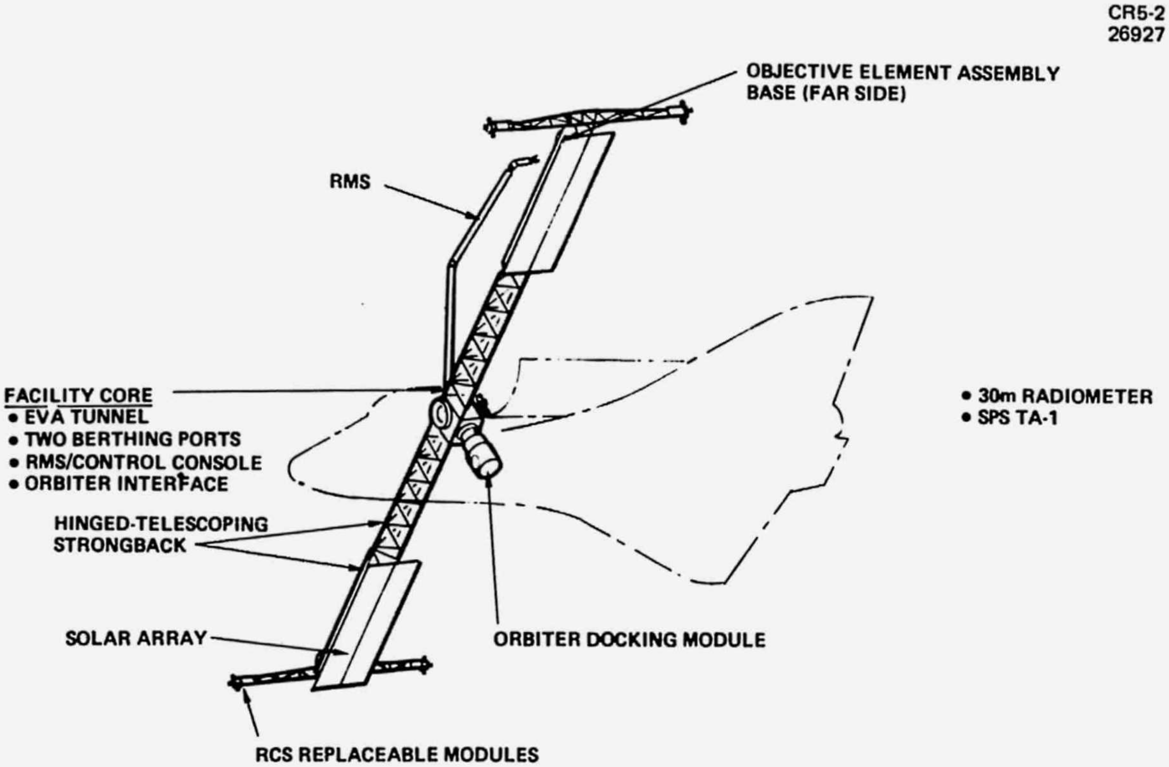

Figure 5-19. Option L' Shuttle-Tended SCB — Double Strongback Configuration with EVA and RMS Control

The primary visible difference in free-flyer subsystems is the use of solar arrays on the strongback beams to provide on-orbit charging of batteries. The result would be a smaller complement of storage batteries and elimination of the need for cycle replacement.

The potential growth benefits of this concept facility components is limited to the strongback itself inasmuch as a design of the assembly jig for SPS TA-2 is possible which is based on additions to the strongback. No other facility components of L'_3 and L'_4 are applicable to the permanently manned SCB.

5.3.4.3 Four-Man Fabrication and Assembly (L'_5 and L'_6)

Figure 5-20 shows a configuration which represents an intermediate level of hardware complexity, and consequent level of capability effectiveness. The concept relies heavily upon the Shuttle provisions and accommodations but provides a pressurized control center as part of the orbital facility. A pressurized tunnel within the core structure provides shirtsleeve transit between the control module and the Orbiter flight deck. EVA may be either

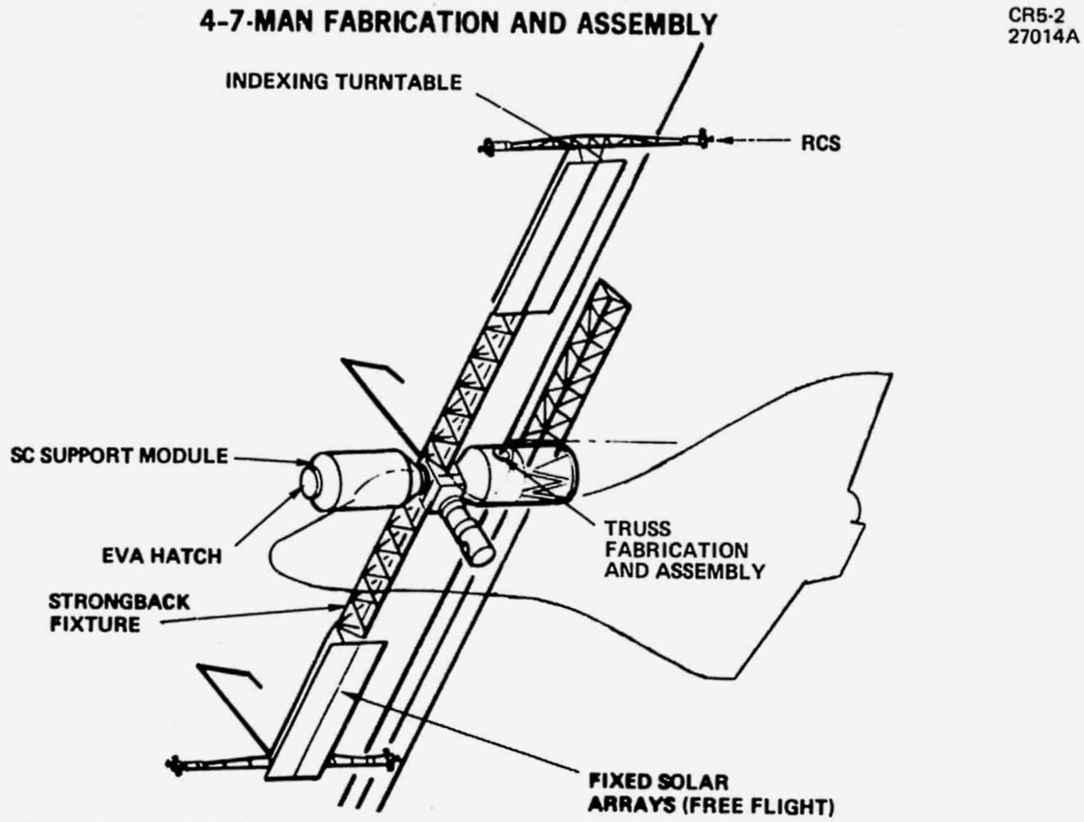

Figure 5-20. Shuttle-Tended SCB Option L′ – Strongback

by the EVA airlock within the control module or via the end of the depressurized tunnel.

The central component of the Orbital facility is the strongback. It consists of two truss beams mounted on a core structure and is virtually identical to that described for $L'_{3,4}$. The core structure consists of a truss box within which is a semimonocoque tunnel. The tunnel has a single side interface with one of two lateral berthing ports. The lateral port which interfaces the tunnel is where the control module is located, while the other port may stow various tooling or logistic modules during the orbital operations. The two truss beams are hinged on the core and are two-segment telescoping beams. The beams may be collapsed and folded into single launch size package. The core tunnel terminates with the mounting structure for a crane, and at the other end, with an Orbiter-compatible docking system.

The beam arms of the strongback mount various equipment including rotating bases for the buildup of objective elements, two-panel solar arrays ($102 m^2$) for housekeeping power during the free-flying mode between Orbiter visits,

ACS thruster/propellant modules, antennas, position and navigation lights, work illumination lights, EVA suit umbilical service panels, EVA mobility and constraint devices, and fixtures and stowage platforms for miscellaneous equipment.

The crane arm, which is mounted on a rotating ring at the end of the tunnel, is selected as an Orbiter RMS unit. In this configuration, however, first choice for the control station is in the berthed end of the control module. View ports may be included in this module to provide visual coverage of assembly operations.

Direct observation of operations associated with the Orbiter's cargo bay or with logistics modules berthed on the opposite side of the core structure are limited and would require television operations for those zones. A control console on the rotating base of the RMS is still the most attractive duty station operationally. As the facility develops with the successive launches, a second crane arm is delivered and is installed on the mounting base on the end of the strongback opposite the support of the objective element. This second arm will expand both the reach and the scope of manipulator operations, especially during TA-1 assembly. This second arm could be another Orbiter RMS unit; however, the program timing and the assembly operations scope would favor an advanced crane arm with a larger reach. This could be the arm which is later to be part of the advance mobile crane of the all-up SCB and provide testing for it.

The new item of significance, with respect to the prior concepts, is the pressurized control module. This is the module that provides the space construction control functions, EVA support, and also the equipment for testing, calibrating and performing checkout of the objective element components and systems, see Figure 5-21. The module would provide growth continuity into the permanently manned SCB phase.

One side of the module contains a one-man control console for the cranes, either primary or backup, and with the display capability to monitor and control all TV viewing, work illumination, and associated operable devices. Adjacent to the control console is an equipment console for computational data (operations) recording or processing, and facility subsystems.

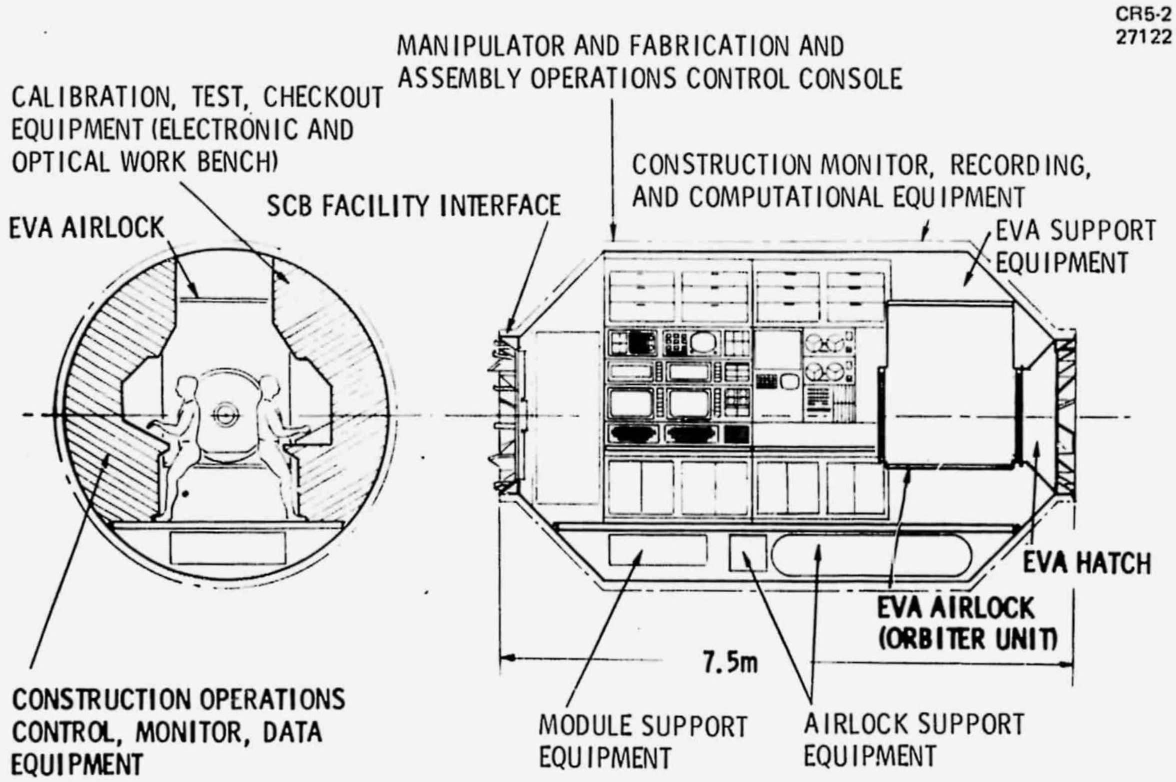

Figure 5-21. Space Construction Support Pressurized Control Module (L'/L)

The other side of the module contains the console equipment and workbench for objective element support. The workbench functions would include electrical or electronic test/work, optical test or alignment, and minimal mechanical operations in support of the test, calibration, and checkout operations.

An EVA airlock is located at the end of the module opposite its facility berthing interface. The airlock which will support two-man EVA operations may be an Orbiter airlock unit. The unit may be located inside the module as shown or may be outside with an end dome design which will allow it to be stowed internally for launch.

The subsystems in this configuration are mixed installation concepts. Those subsystems which exclusively support the free-flying phases between Orbiter visits are still strapdown, highly modularized systems which favor replacement rather than replenishment. Those subsystems addressed to space

construction operations or the facility support during manned periods may be integrated into the structures and have interfaces which will allow integration with SCB (L) development.

The components in this configuration fit well with a growth plan to the permanently manned SCB (L). Figure 5-22 shows the results of such a buildup from the $L'_{5,6}$ facility. The Shuttle-tended configuration may be developed into a large-scale, permanently manned facility by the addition of modules that provide the capacity for unattended manned operations of appreciable duration. The basic L' facility strongback and attached control module are retained. The facility is developed primarily by the addition of modules along the original Orbiter docking axis.

The original strongback truss beams may have additional structure added to provide the basis for a construction tool for the TA-2 objective element. After the strongback is built into an appropriate framework, longeron fabricating modules, rolls of array surface materials, automated robots, and other equipment complete the fixture, and the construction of TA-2 may begin.

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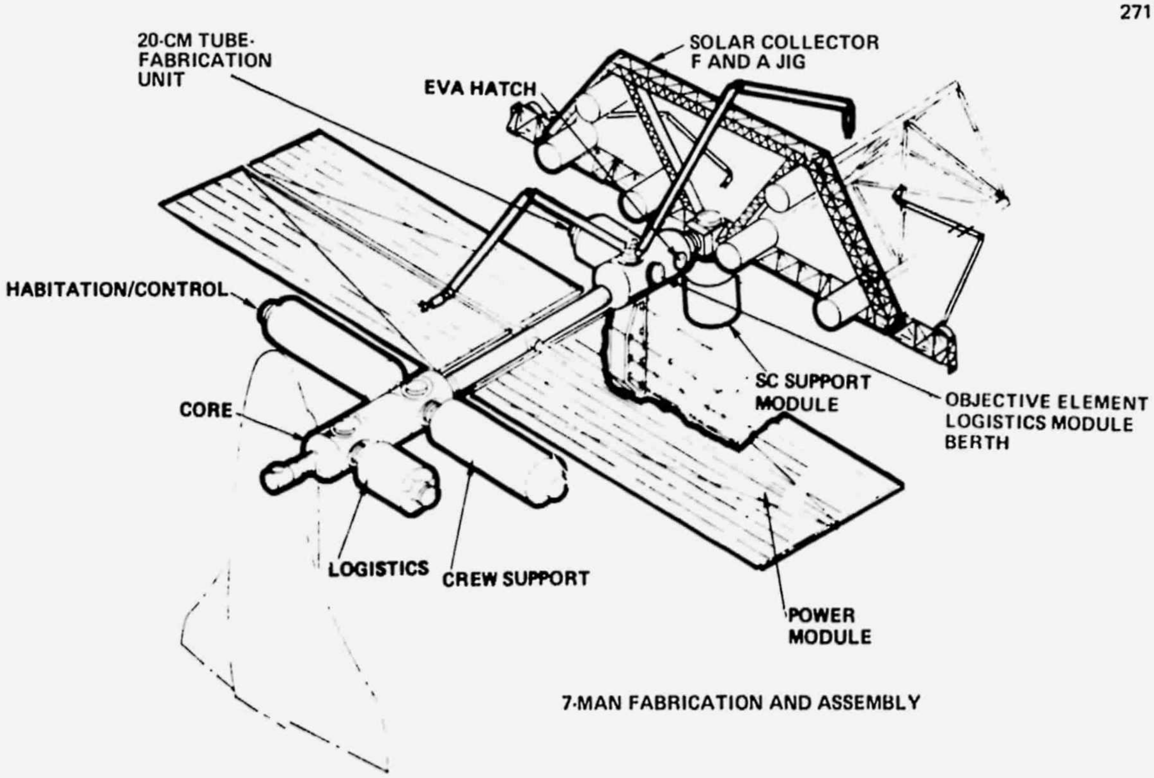

Figure 5-22. Option L Permanently Manned SCB — Strongback

5.3.4.4 Single Launch Option (L'_7 and L'_8)

The single Shuttle-launched/Shuttle tended configuration (L'_7 and L'_8) represents a further increased capability with an inherent flexibility of direct growth to a permanently manned SCB. The L'_7 orbital facility consists of a space construction support module and a simple truss-type strongback on which to assembly the objective element.

The primary element is the Shuttle-tended SC support module shown in Figure 5-23. This module contains capabilities for electrical power, limited guidance and control, propulsion, communications, and crew EVA operations. Data management, internal atmosphere, thermal control, and crew life support systems are provided by the Orbiter. The cylinder diameter is 4.419m (14.5 ft), with protrusions out to 4.6m (15 ft) diameter and 18.28m (60 ft) in length, using the full Orbiter capability. The diameter is common with other SCB modules. The solar array turret located amidship has a 1.0m (3 ft, 4 in) minimum inside diameter between the two basic compartments.

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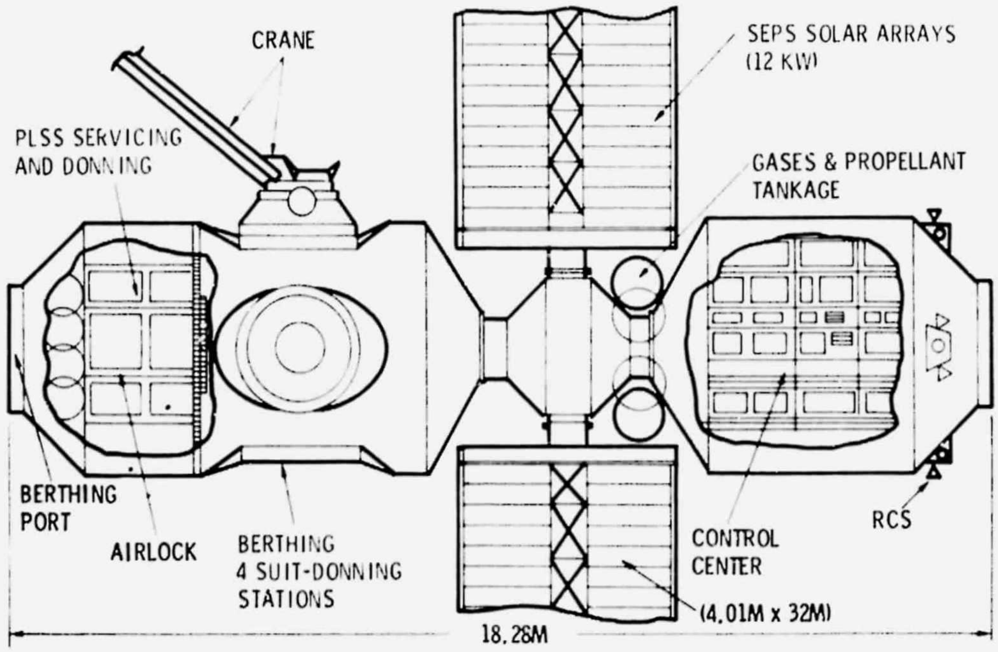

Figure 5-23. Space Construction Support – Single-Shuttle Launch

Externally, the module is divided into two compartments separated by the solar array turret. Two end berthing ports, one passive and one active, plus four passive radial berthing ports, are incorporated. The hatch in each of these ports provide a 1.0m diameter minimum clear opening. Each hatch contains a central 0.2m (6 in) diameter window. The pressure shell is encapsulated in a meteoroid shield and radiator with high-performance insulation. Four thruster modules are located on the co nical end dome furthest from the objective element. A two-arm manipulator mobile crane provides control, movement, and dexterity needed in the buildup process of the objective elements. The crane arms provide approximately a 35m reach from the berthing port at which the crane is located. The remaining radial berthing ports would be reserved for logistics and tooling elements and the end axial port would be used for objective element buildup or final assembly. Internally, the smallest cylindrical section houses the electronic equipment, including the power distribution equipment, communications, crane operations and control, EVA monitoring equipment, and flight controls. The larger compartment accommodates the radial berthing interface and access to the various objective element tooling or logistic pallets. All EVA activity is supported from this section. An EVA airlock of 4-man capacity is incorporated to provide adequate volume for PLSS donning and servicing. In addition to the berthing port hatch, a side EVA hatch is provided. A pressure bulkhead separates the airlock volume from the remainder of the compartment.

Pumpdown equipment and gas storage would be provided in the compartment. The solar array gimbal turret separates the two module compartments and incorporates an SEPS-type solar array. The arrays are packaged in a retracted position within the 4.572m (15 ft) dynamic envelope. When deployed, the solar arrays are 256.6m^2 (2,761 ft^2) in area. The solar array turret can be pressurized and serviced in a shirtsleeve environment. The solar arrays are retractable, permitting the module to be a basic component of the full-capacity SCB.

The strongback consists of a hinged, folded truss beam attached to the SC support module. The beam is a trussed triancular cross-section, foldable to be compatible with the Orbiter cargo bay. The free end of the beam incorporates provisions for installation of an indexing turntable for mounting

objective elements. Configuration L'_8, Figure 5-24, incorporates the same SC support module and strongback fixture, but also possesses a truss fabrication and assembly module to fabricate small tubes and to provide an assembly jig for trusses. Each configuration has the flexibility for growth into a permanently manned SCB.

The development of the single-launch L' facility into the permanently manned SCB facility, Figure 5-25, is via the addition of modules to increase the functional capacities and to add the capabilities for unattended orbital operations. Since this L' derivative concept started with the advanced long-reach crane and the all-up 4-man airlock, the primary add-on requirements are a large electrical power system and expanded permanent crew habitation and additional berthing capability.

The add-on EPS module is a large area array capable of supporting all the facility housekeeping, construction operations, objective element testing

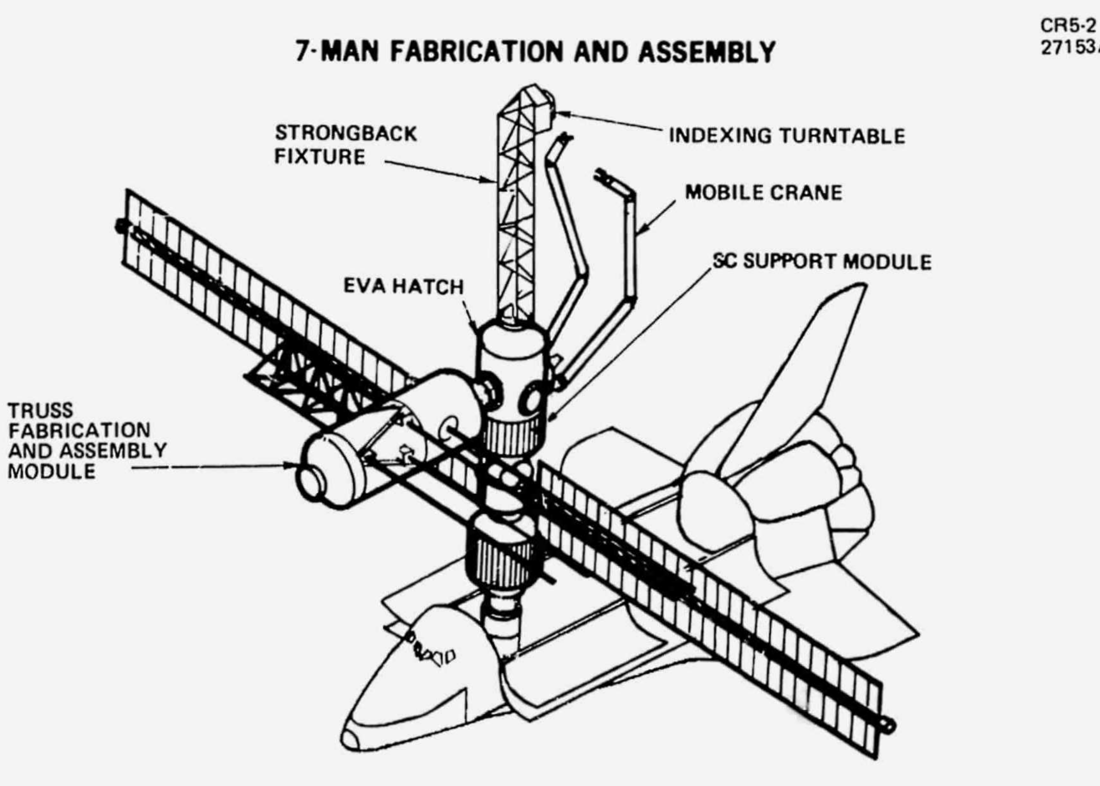

Figure 5-24. Option L' Shuttle-Tended SCB – Single-Shuttle Launch

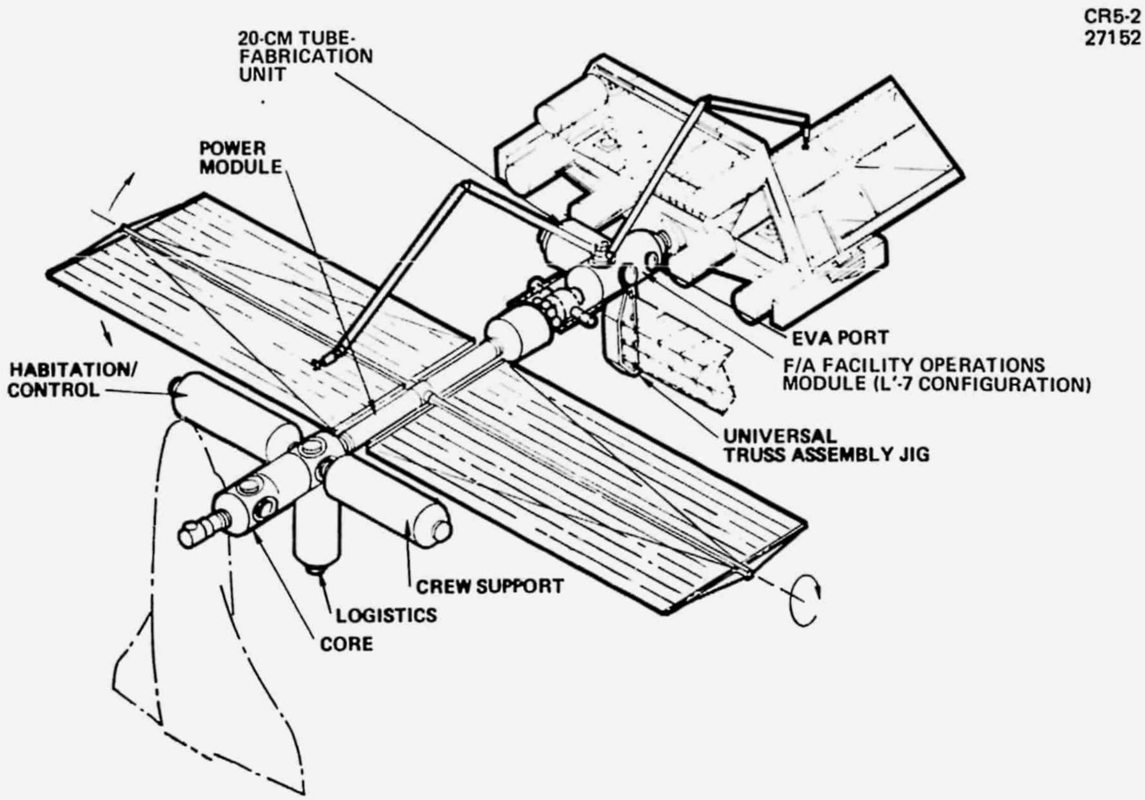

Figure 5-25. Option L Permanently Manned SCB — Single-Shuttle Launch

including space processing operations. A core module is added to which habitation, space processing, and logistics modules, and orbiter docking are provided.

To support the construction of TA-2 objective element, a large, multi-segmented solar collector fabrication and assembly jig is added to the longitudinal axis of the support module, while a composite tube fabrication module and a universal truss assembly jig is added to the lateral/berthing ports. Along with material logistics modules, these facilities accommodate the construction of TA-2 linear array structure from the solar collector jib along the SCB's longitudinal axis.

5.3.4.5 SCB System Option L'_9 and L'_{10}

The Shuttle-tended configurations L'_9 and L'_{10} represent total capability to perform all objective element fabrication and assembly requirements with the inherent capability of direct growth to a permanently manned SCB. The L'_9 orbital facility, Figure 5-26, consists of a core module, power module, SC support module, and a simple truss-type strongback on which to assemble the objective elements.

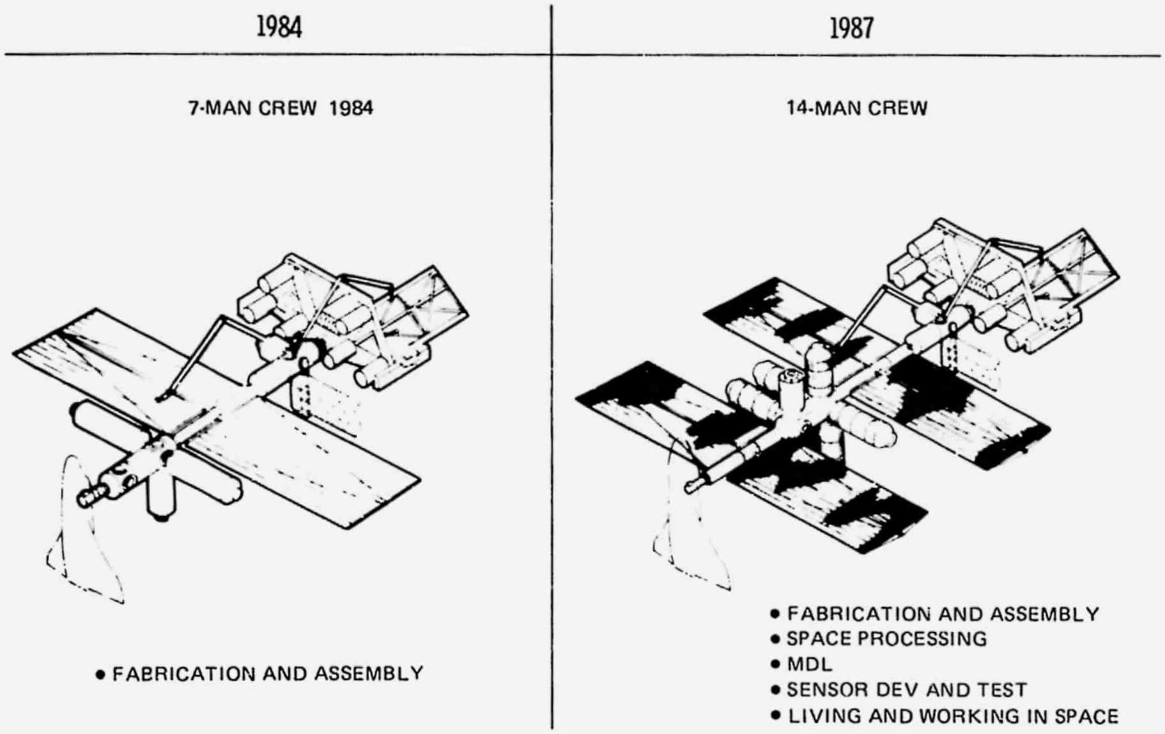

Figure 5-26. Option L SCB Configuration Evolution — Permanently Manned

The initial module delivered to orbit is the core module. The module is 4.41m (14.5 ft) diameter x 15.28m (50 ft) long with eight radial berthing ports and two axial ports. The module accommodates the primary power bus, power conditioning equipment, initial power supply, guidance and control systems, RCS engine quads, coolant loops, and certain monitoring and control electronics.

Following rendezvous and docking of the core module with the Orbiter, the power module is berthed to the core module along the X axis. The power module selected incorporates a solar array of 1,067m^2 (12,500 ft^2) surface area which has the capability of delivering 34 kW power to the bus. However, since Option L'_9 and L'_{10} only requires a small percentage of the total power available, the arrays are only partially deployed to satisfy power requirements at each stage of cluster assembly. The power module boom is 2.24m (88 in) in diameter x 15.84m (52 ft) long and houses the high-pressure storage tanks. The boom operates in a pressurized mode, and the solar array orientation drive mechanisms are maintainable in a shirtsleeve environment.

The third module added to the cluster is the space construction support module shown in Figure 5-27. The module is 4.41m (14.5 ft) in diameter x 15.2m (50 ft) long and incorporates four radial berthing ports and two axial ports. The interior of the module emphasizes maximum usage for crane control, crew support, and EVA preparations. Assembly or fabrication is accomplished in the immediate vicinity of the module by attaching the strongback structure previously defined, or by attaching assembly jigs, fabrication modules, and etc. Thus, the crane can transport material directly from the Orbiter or material canister or pallets directly to the jigs and fixtures. The EVA airlock section provides for a 4-man crew operation with backup gear for one additional man.

With the addition of the composite tube fabrication module and universal truss assembly jib, the SCB is configured to perform fabrication of selected objective elements components and assembly of those elements in a Shuttle-tended mode, L'_{10}.

Direct growth to a permanently manned facility is made possible by the addition of habitation modules to the core module.

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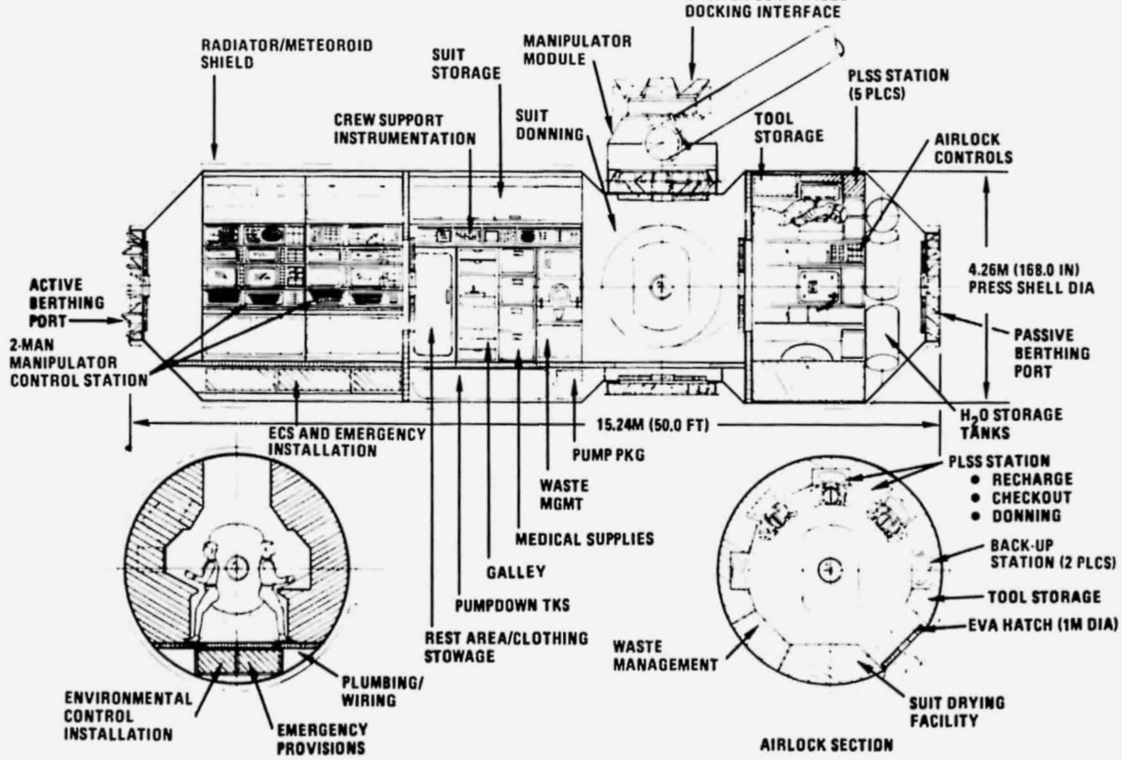

Figure 5-27. Space Construction Support Module

5.3.5 SCB Permanently Manned Concept – Option LEO (L)

The Part 2 SCB concept definition emphasized support of selected objective elements. To expose the requirements associated with the major objective elements that affect the configuration, each major element was defined in sufficient detail to identify the full range of candidate modules. Detailed descriptions of each objective element are provided in Section 3. The Option L configuration is a low-earth-orbit-only configuration capable of accommodating the following mission objective elements:

- 30m Radiometer
- SPS TA-1
- SPS TA-2
- Space Processing (Development and Optimization)
- Sensor Development and Test
- Multidiscipline Laboratory (MDL)
- Living and Working in Space (LWIS)

A permanently manned SCB has two major divisions, standard modules, and a space construction facility, which are relatively autonomous and provide two sets of hardware which can be conceptually addressed through essentially independent tasks. These two divisions are shown in Figure 5-28. In conjunction with the objective element hardware, these two groups can be arranged in different combinations to meet functional and operational requirements. Increased levels of detail provide the alternate concepts necessary to create the fundamental building blocks that provide the inherent flexibility necessary in the class of SCB under study.

Figure 5-18 identifies the primary items and directly relates them to the system option. The items are divided into two groups: functional items and operational items. The figure shows the importance of the objective elements, which will change during the SCB's operational life, but provide design drivers in the form of requirements definition.

In order to define the most desirable SCB system options, various factors were considered as being the primary design and cost drivers including support requirements, construction techniques, crew considerations, SCB orientation, material handling techniques, types of subsystems, and growth capabilities.

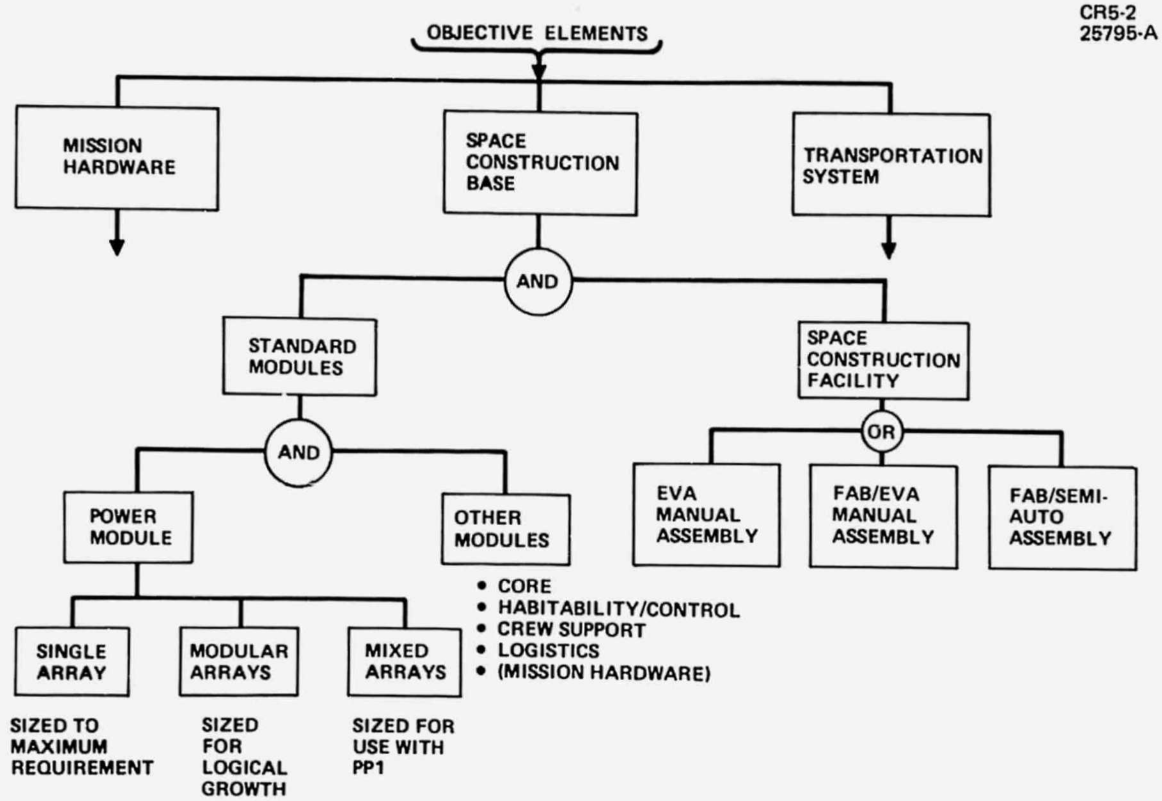

Figure 5-28. How System Options are Developed

5.3.6 Primary Design and Cost Considerations

5.3.6.1 Objective Element Requirements

As noted in the objective elements definition and program descriptions, objective elements were selected on the basis of early potential and applicability to the initial program time frame of 1984 to 1987. The objective elements were defined to provide detailed support requirements to be imposed on the SCB in each of the program options. This approach permitted a realistic analysis and conceptual design of the SCB.

The information shown in Table 5-13 was used to develop the objective and performance characteristics for Program Option L SCB concepts. Generally, the power required for fabrication and assembly operations is relatively low with the exception of test requirements for SPS TA-1. The power timeline schedule has taken into account the basic fabrication and assembly operations as well as the test requirements for each objective element. Power for the general mission support equipment is in addition to that for the noted objective elements.

Table 5-13

SPACE CONSTRUCTION (L) OPERATIONAL SUPPORT REQUIREMENTS

Objective Element	Minimum Crew		Power			
			Average		Peak	
	Fab and Assy	Test	Fab and Assy	Test	Fab and Assy	Test
SPS TA-1	3	1	6 kW	5 kW	10 kW	80 kW (~0.5 hr)
SPS TA-2	3	2	9 kW	2 kW	12 kW	4 kW
30m Antenna-Radiometry Satellite	3	2	2 kW	2 kW	4 kW	4 kW
Bioprocessing	3		4 kW		8 kW	
Ultrapure Glasses	4		20 kW		30 kW	
Shaped Crystals	3		12 kW		18.5 kW	
Living and Working in Space	<1 ('84-'87)	<2 ('87-)	0.5 kW→1.0 kW		Not applicable	
Multidiscipline Laboratory	1 to 6		2 kW to 12 kW		16 kW	
Sensor Development	2		10 kW		12 kW	

The space processing objective category identifies high power requirements in the space development of ultrapure glasses and shaped crystals. It requires appropriate scheduling of these objective elements in Program Option L to maintain total bus power at a level compatible with a single power module (i.e., an approximate 35 kW at end of life). The noted power levels include all power requirements for the space processing modules. Requirements shown are for fully dedicated crewmen for the durations of the space processing development phases.

Space cosmology requirements, involved with antenna assembly, are identical to those for assembling the radiometry and multibeam lens antennas. Power and crew requirements for living and working space are small, involving one to two racks of equipment (depending upon the time period in question), and may be performed as other objective element schedules permit. Crew requirements for MDL R&D are a variable depending upon the priority of the work and the availability of base resources. Sensor development will require two crewmen and 10 kW of average power to meet its objectives.

5.3.6.2 EVA Support Requirements

The preliminary groundrules for SCB EVA shown in Table 5-14, were developed in coordination with the MDAC subcontractor, Hamilton Standard. Since crewmen may work 6 hours a day on 180-day tours, it is desirable to limit continuous EVA to 3 hours, and daily EVA to 6 hours. As EVA experience is gained with the Shuttle and Space Station, it may be possible to extend these times.

Table 5-14

PRELIMINARY EVA GROUND RULES

EVA Work Period: Two 3-hour periods with 2-hour interim
Pre/Post preparation: Pre-EVA – 40 min Post EVA – 30 min
10-minute rest period every 2 hours (in-suit refreshment)
6-day week
One to two EVA crewmen cherry picker
Energy expenditure: 900 average btu/hr
Minimum two-man EVA crew
No backup man in airlock
Suit can be dried between shifts
Independent life support suit (no umbilical)

The overhead figures for pre- and post-EVA preparation are conservative and in actual practice will probably be less than those shown. From a safety standpoint it was felt that since two men will be performing EVA at the same time (therefore acting effectively as safety buddies), no standby suited crewman in the airlock will be necessary. Though suits will have independent life support systems, this does not preclude the necessity for having the capability to support the suit with an umbilical under some conditions.

For any EVA in which the crewman must exert force, one of the most important requirements is that he be sufficiently restrained to counteract such force. Additionally for SCB EVA, the crewman must perform assembly operations at varying locations as the work progresses, and must translate from the airlock to the work location and back.

Four alternatives for satisfying the above requirements were evaluated as shown in Table 5-15. Restraining the EVA crewman on either a one- ot two-man work platform attached to the end of a crane or remote manipulator boom appears to offer the most flexibility in meeting the EVA requirements. This approach has a potential disadvantage in that the work location envelope is limited by the length of the boom and the maneuverability of the crane itself.

Table 5-15

EVA ACCESS CONSIDERATIONS

	Advantage	Disadvantage
Mission hardware-mounted restraint	Minimum complexity	Severe restrictions on equipment available and handling capabilities
Scaffolding	"Global" access to work	Number of pieces, erection-teardown time, size limitations
Mobility mechanisms	Can be relatively simple	Special-purpose equipment for each task
EVA work station cherry picker	"Global" access to work, convenient support function location	Probably highest development cost

For precision EVA operations it will be necessary to control crane dynamics or to somehow restrain the cherry picker platform, to prevent oscillation of the work station.

The cherry picker work station offers the additional advantage that auxiliary crane controls, tool storage, power and life support outlets, and displays can be mounted on it, thus making these facilities available to the crewman at any work location.

5.3.6.3 Construction Techniques

There are basically five variations on the types of space construction techniques which are applicable to the SCB:

- Deployable Structures — These types are generally limited in size, however surface precision may be a problem and may require EVA assistance for final adjustments.

5.3.6.4 Crew and Habitability Considerations

Study activity for the crew and habitability subsystem consisted of: (1) review of subsystem baseline requirements for the various program options; (2) synthesis of requirements necessitated by the program options considered; and (3) impact of requirements imposed by the various program options on the baseline configurations. Only a brief summary of the activity will be presented herein; Volume 3, Book 2 gives a more detailed description.

Two basic program approaches were addressed, i.e., the permanently manned (L) option, and the Shuttle-tended (L') option. In considering the permanently manned configuration, eight general categories of the crew and habitability subsystem, along with elements included under each category, were discussed. Where significant differences between baseline requirements and the requirements imposed by Options L and L' occurred, these were defined and potential impact of the differences were discussed.

In addition, areas requiring further investigation were identified and potential trade-offs suggested. Also, areas sensitive to increases in crew size, specifically 14- and 21-man crews, were identified and their impact on option L and L' configuration crew and habitability subsystems were discussed.

It was concluded that the increased crew size and extended mission durations associated with Options L and L' impacted many aspects of the baseline crew and habitability subsystems. This was particularly evident in the case of Option L', where the most significant impacts were found in the free volume, logistic support, and waste management.

- Manual Assembly — Manual, or erectables can be used to increase structure size and surface precision. This type of structure requires complete EVA support for handling and control of payload elements.
- Auto assembly — Autoassembly is desired if structure is very large with excessive number of components and operation procedures. This requires that a preprogramed crane and/or robots be incorporated to perform assembly tasks.
- Orbital Fabrication and Manual Assembly — Orbital fabrication techniques are desirable for very large structures to maximize Orbiter payload capability. This requires on-orbit facilities to preform tubing, angles, etc., in addition to the support of EVA activities.

- Orbital Fabrication and Autoassembly — This combination of activities imposes the greatest demand on the SCB configuration, requiring tooling, fabrication equipment, assembly fixtures, automated robots, and EVA accommodations.

5.3.6.5 Material Handling

Man's capability to maneuver equipment modules and objective elements is limited and greatly dependent on assisting mechanisms. The program operational requirements and characteristics defined in Section 5.3.5.1 establish requirements to assemble the SCB modules, assemble large space structures, and handle local logistics. The SCB support system selected must consider module size, quantity of material, configuration, mass, distance, time, temporary storage, and dynamic influence on SCB.

Several options were investigated as shown in Figure 5-29, with the mobile crane selected as baseline. A detailed description of the crane is found in Volume 3, Book 2.

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	RAIL TRANSFER	SWING BOOM	MOBILE – WALKING	STATIONARY MOUNT
PROS	• GOOD AXIAL MOBILITY • CONTROLLED MOTION • RAIL POWER/ COMMANDS LINK	• ALL BERTHING PORTS AVAILABLE • CONTROLLED MOTION • RAIL POWER/ COMMANDS LINK	• 3-D MOBILITY • SCB GROWTH FLEXIBILITY • SPACE CONSTRUCTION VERSATILITY	• LEAST COMPLEX • POWER AND COMMAND LINK HARDWIRED
CONS	• CLEAR CORRIDOR • 2-D MOBILITY • RAIL BLOCKS BERTHING PORTS • BRIDGE AT SOLAR ARRAY TURRET	• COMPLEXITY • CANTILEVIER BEAM LENGTH • SPACE CONSTRUCTION INTERFERENCE • CLEAR CORRIDOR	• REQUIRES BERTHING PORT • POWER PICKUP PADS	• TWO CRANES REQUIRED • CLEAR CORRIDOR • HANDOFF ITEM TRANSFER • SCB GROWTH CONSTRAINTS

Figure 5-29. Subsystem Option SCB Crane Trades

5.3.6.6 Orientation Considerations

An understanding of the effects of orientation of the SCB in its variety of configurations is important to a good understanding of the design requirements and logistics resources. Of primary interest for this study were the requirements placed on the guidance and control, reaction control, and electrical power subsystems. The amount of impulse required for orbit-keeping and attitude control was determined for a variety of orientation configurations with both the Orbiter and a representative mission hardware objective element attached to the SCB. A particular configuration was chosen for analysis of the amount of shadowing of the solar arrays for the electrical power subsystem.

Four configurations, three B-angles (the angle between the sun vector and the orbit plane), and three orientations were simulated and analyzed. The results show that to minimize orbit-keeping and attitude control requirements over a long time interval, an orientation with the principal axes of inertia, rather than the geometric axes, aligned to the center of the earth reduces the propellant usage from approximately 20 to 1.5 kg per day for the simplest configuration, and from approximately 200 to 5.7 kg per day for the most complex configuration. It is also interesting to note that drag variations with orientations were not severe (3:1 for the simplest configuration and approximately 1:1 for the most complex), indicating a high flexibility to allow a long-term minimum moment orientation. Earth shadowing effects (maximum of 39%) appeared to be more important than vehicle shadowing effects (maximum average of 12%) on the vehicle solar panels. The analysis techniques and results are described in Volume 3, Book 2.

5.3.6.7 Solar Array Considerations

The SCB must be configured into Orbiter-transported modules which are assembled on-orbit. The final assembled modules must house and support subsystems, flight crew, and objective elements at both the initial manned level and at the growth levels. The SCB requirements can be satisfied by three basic options: solar array amidship, solar array end-mounted on the X-axis, and two solar arrays on the Y-axis. A summary of these basic options is shown in Figure 5-30. Since each module of the SCB is essentially

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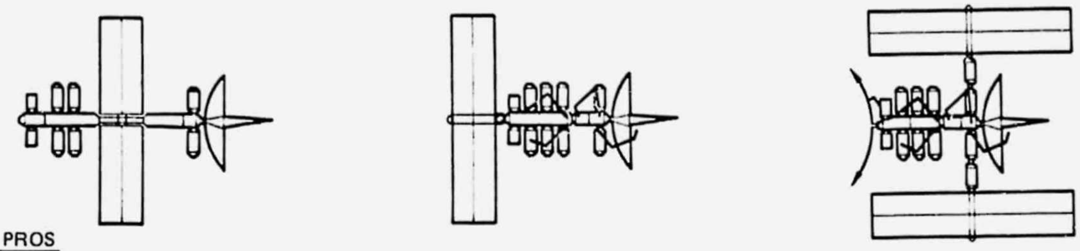
SOLAR ARRAYS AMIDSHIPS ON X-AXIS	SOLAR ARRAYS END MOUNTED ON X-AXIS	SOLAR ARRAYS TWO POWER MODULES ON Y-AXIS



	SOLAR ARRAYS AMIDSHIPS ON X-AXIS	SOLAR ARRAYS END MOUNTED ON X-AXIS	SOLAR ARRAYS TWO POWER MODULES ON Y-AXIS
PROS	• ORBITER AWAY FROM SOLAR ARRAYS • FAB/ASSEM ISOLATED • PERMANENTLY MANNED DIRECT BUILDUP	• ATTITUDE LESS CONSTRAINED • POWER MODULE ACCESSIBLE FOR REPLACEMENT • MINIMUM SHADOWING	• ATTITUDE LESS CONSTRAINED • TWO POWER MODULES • POWER MODULE(S) ACCESSIBLE FOR REPLACEMENT • MINIMUM SHADOWING
CONS	• ATTITUDE CONSTRAINED ARRAY/RADIATOR SHADOWING • SOLAR POWER LIMITED • POWER MODULE REPLACEMENT DIFFICULT	• ORBITER ADJACENT TO SOLAR ARRAYS • FAB/ASSEM ADJACENT TO HABITATION MODULES • MODULE TRANSFER ACROSS SOLAR ARRAYS • INHIBITS GROWTH	• POTENTIAL SPACE CONSTRUCTION INTERFERENCE • COMPLEX BUILDUP • MOBILE CRANE REQUIRED • MAY REQUIRE ARRAY SUPPORT STRUCTURE

Figure 5-30. SCB Configuration Options Element Location Trades

a different spacecraft, the minimum number of modules that will provide adequate resources and meet the launch constraints of volume and weight must be the solution. Therefore, the configuration option with the solar array amidship was selected as the baseline-permanently manned SCB.

5.3.6.8 SCB Definition and Characteristics

The selected SCB configuration is shown in its 7-man cluster arrangement in Figure 5-31. The SCB is composed of five basic modules: core module, power module, space construction support module, crew support module, and a habitation/control module. It contains accommodations for seven crewmen and necessary support functions for all the identified objective elements.

The basic elements of the SCB, in addition to the habitation elements, include the fabrication and assembly facility. This facility consists of the space construction support module, mobile crane, composite tube fabrication module, universal truss assembly jig, and solar collector fabrication and assembly jig. Following deployment of the fabrication and assembly facility tooling, the objective elements can be installed.

Each objective element defined interfaces with the basic SCB element, enabling the facility to fabricate the necessary components and assemble both tooling and mission elements, thus maximum use is made of the basic units of the SCB. The SCB is powered by a 1,067m^2 (12,500 ft^2) 34 kW solar array deployed to the power level required at various SCB buildup configurations. Twelve radial berthing ports and two axial docking port are incorporated to accommodate base elements. Two radial ports will be used for logistics modules with the remainder allocated to habitations and/or mission objective elements. The on-orbit arrangement places the power module amidship between the core module and the space construction support module, thus providing the maximum separation of Orbiter docking, crew habitation, and construction activity.

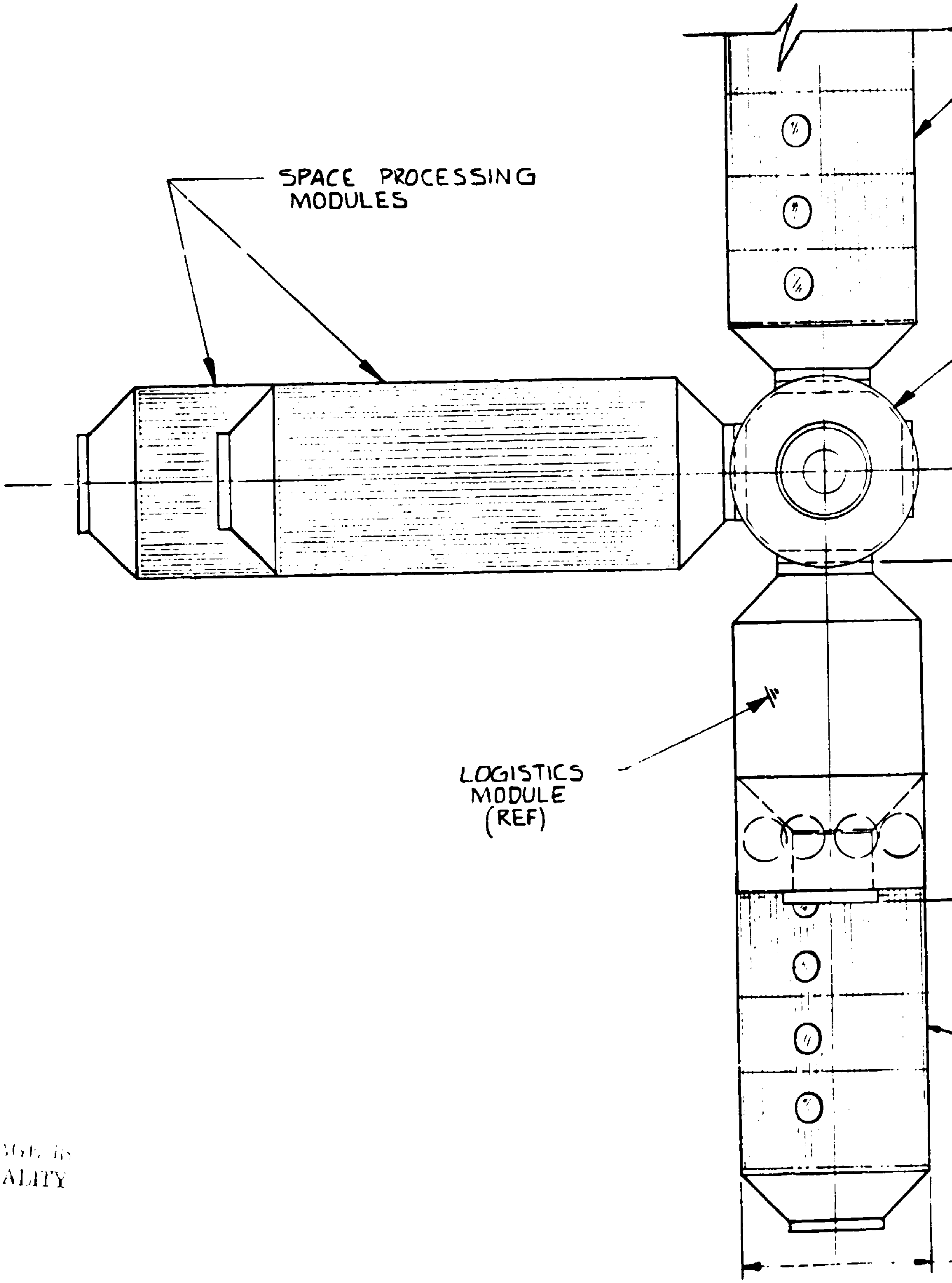
- SCB Buildup

The initial module delivered to orbit is the core module. After the operational integrity of the core module has been verified by the Orbiter crew, the module is released and deployed. The core module RCS and control system will stabilize the module in a gravity gradient attitude. The module is left in a nominally quiescent state until the scheduled power module launch.

After the core module has been berthed to the Orbiter, the power module is deployed from the Orbiter payload bay and berthed to the X axis on the core module. After verification of subsystems, the module cluster is released.

Approximately 60 days after the core module is launched, the SC support module is launched. After the Orbiter accomplishes rendezvous and docking with the core module cluster, the SC support module is deployed from the Orbiter cargo bay by means of the PIDA. After verification of subsystems, the SC support module is removed from the PIDA by the mobile crane and berthed to the power module. The SCB is now configured to perform the construction activity associated with the major objective elements in a Shuttle-tended mode.

To permanently man the SCB, the crew support module and the habitation/control module are added for the 7-man crew support. The habitation modules are radially berthed to the core module by use of the SCB mobile



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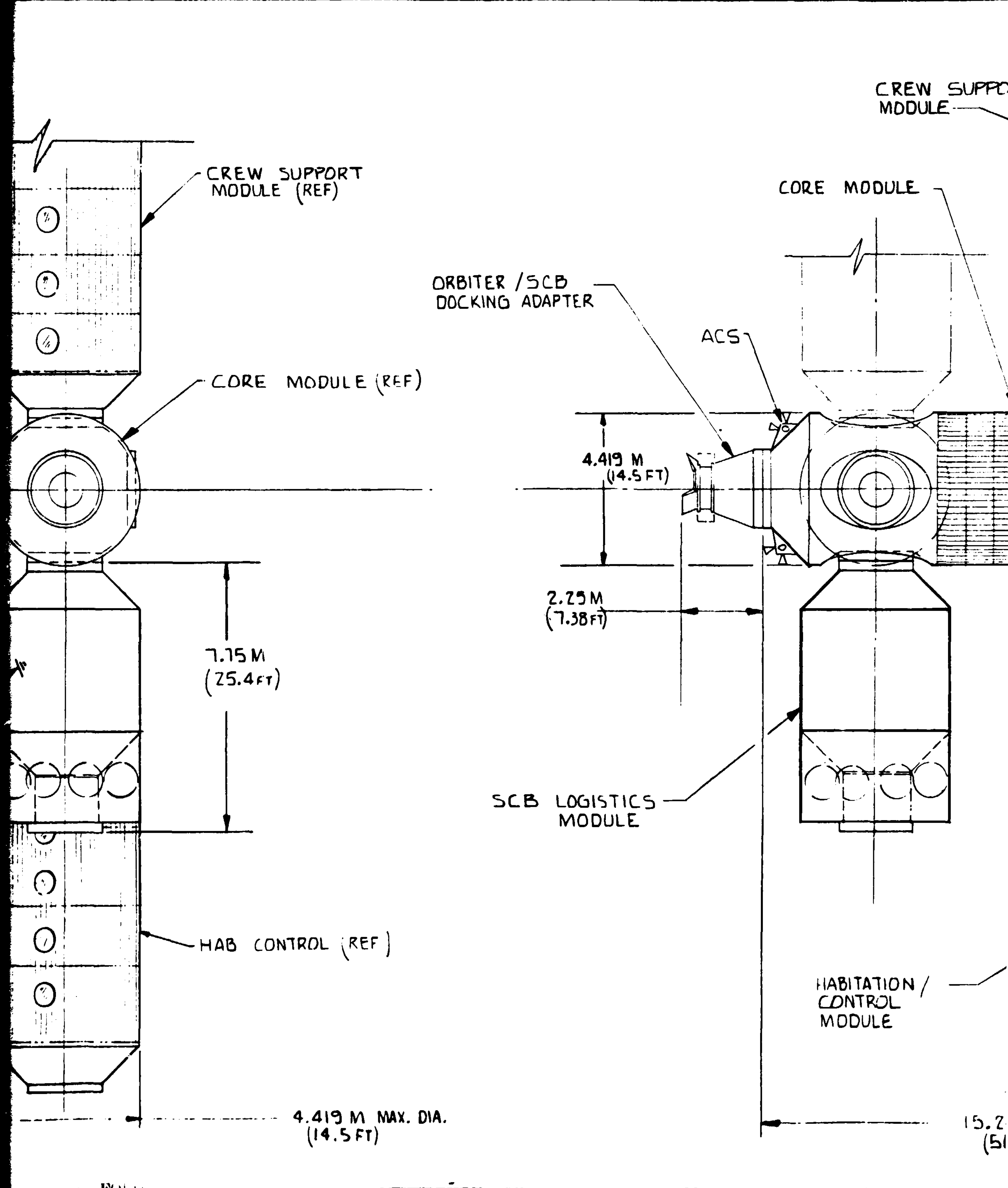

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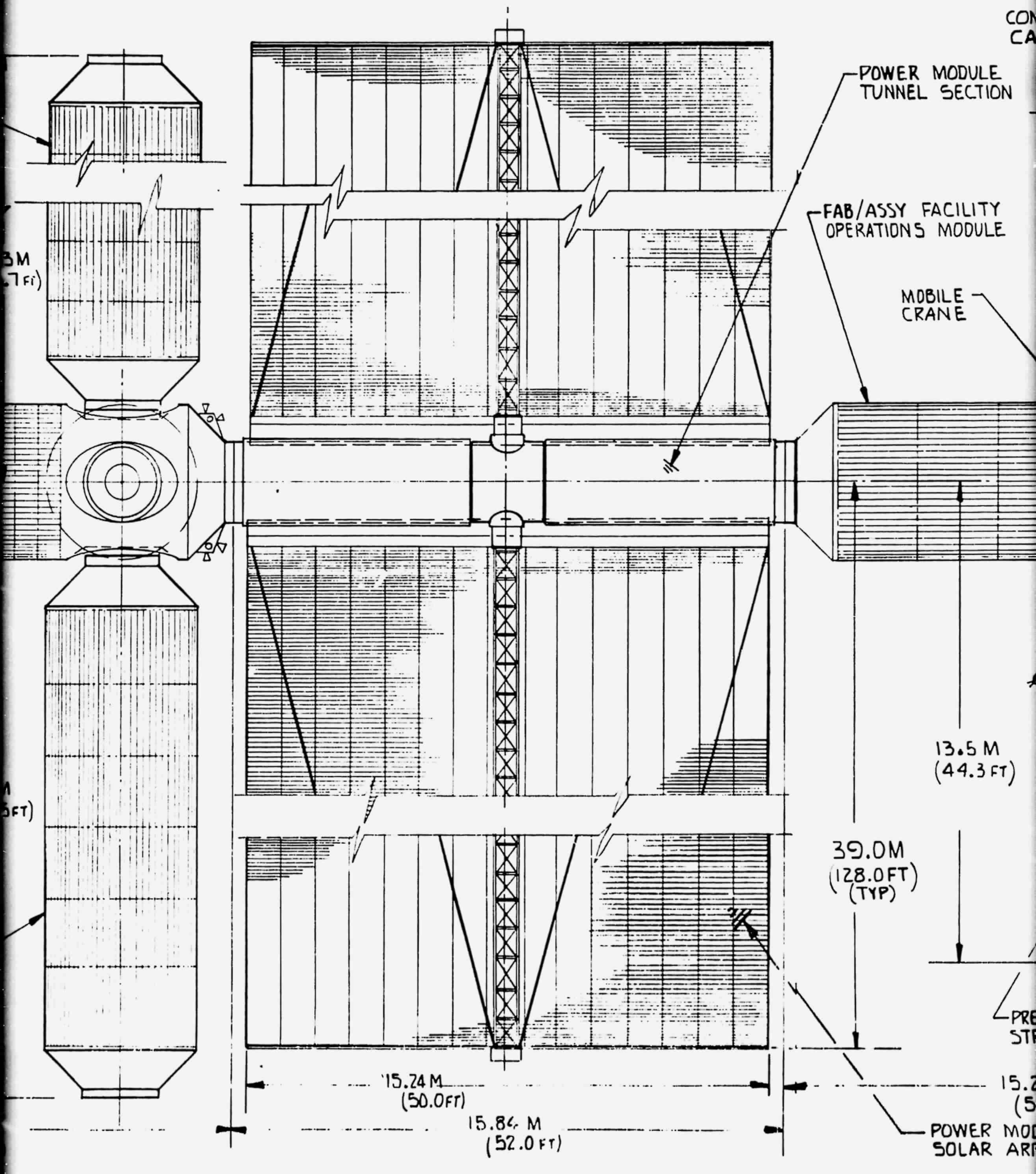

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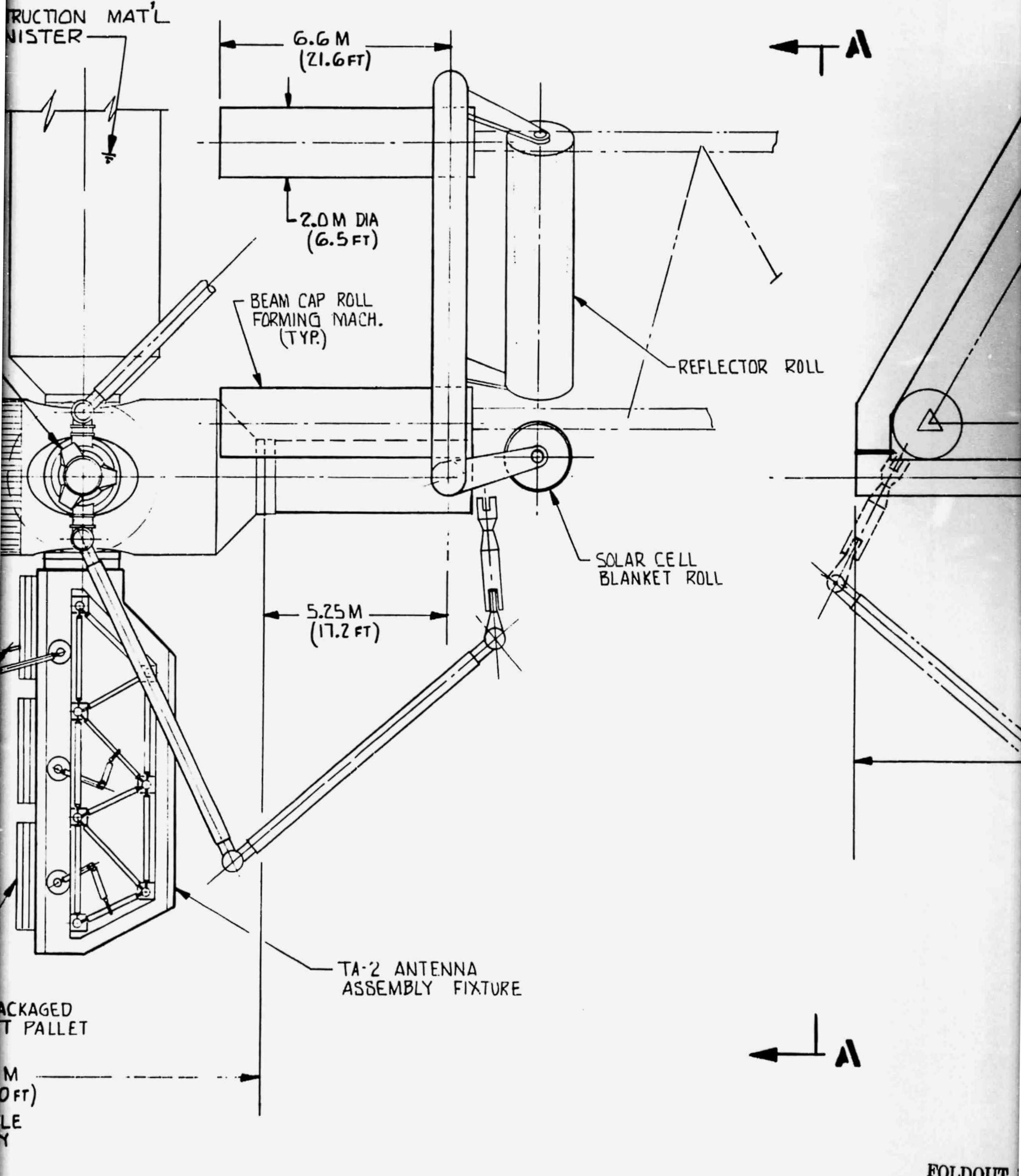
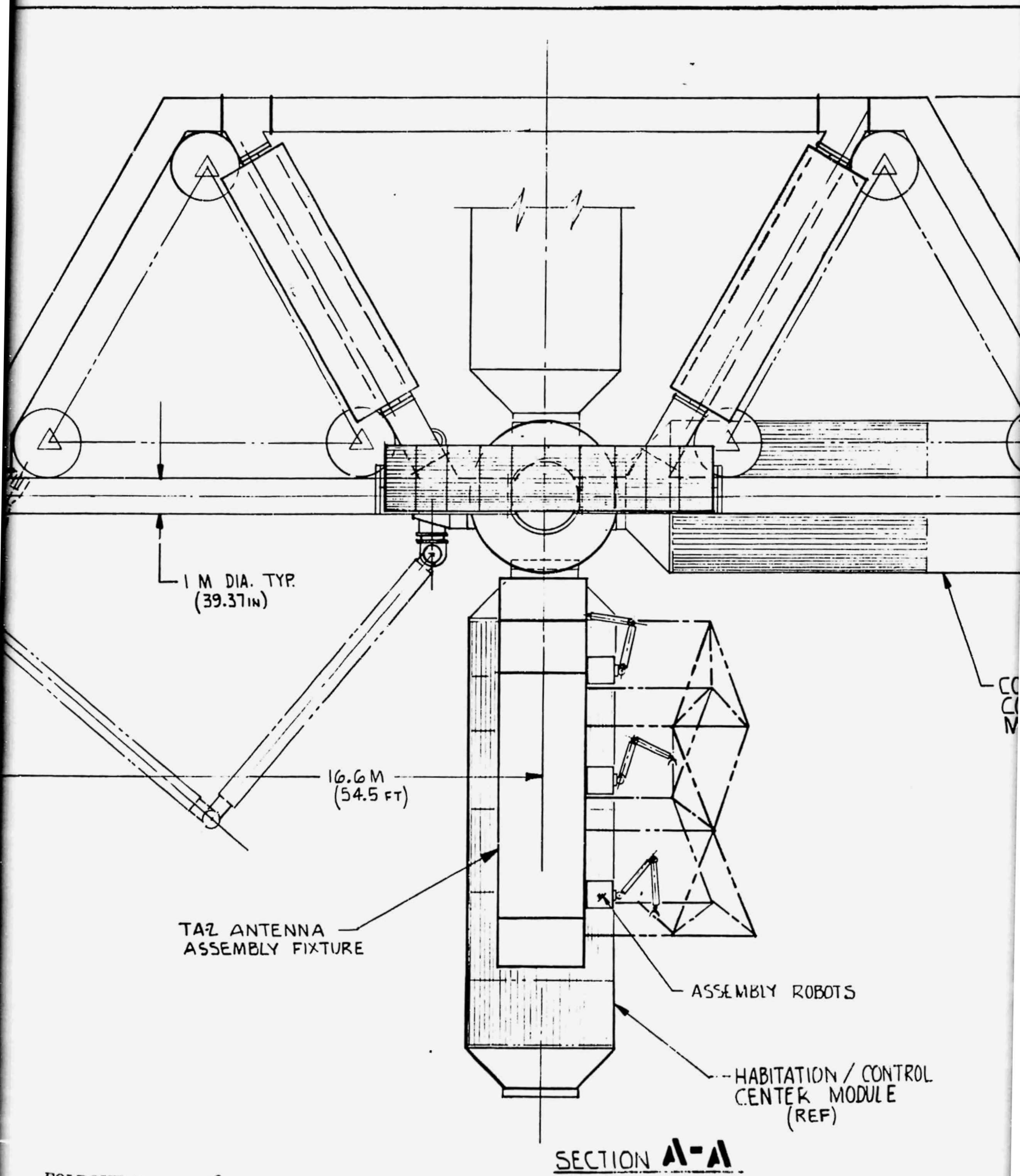


RUCTION MAT'L
NISTER
6.6 M
(21.6 FT)
A
2.0 M DIA
(6.5 FT)
BEAM CAP ROLL
FORMING MACH.
(TYP.)
REFLECTOR ROLL
SOLAR CELL
BLANKET ROLL
5.25 M
(17.2 FT)
TA-2 ANTENNA
ASSEMBLY FIXTURE
ACKAGED
T PALLET
M
0 FT)
LE
Y
A



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FOLDOUT FRAME 5

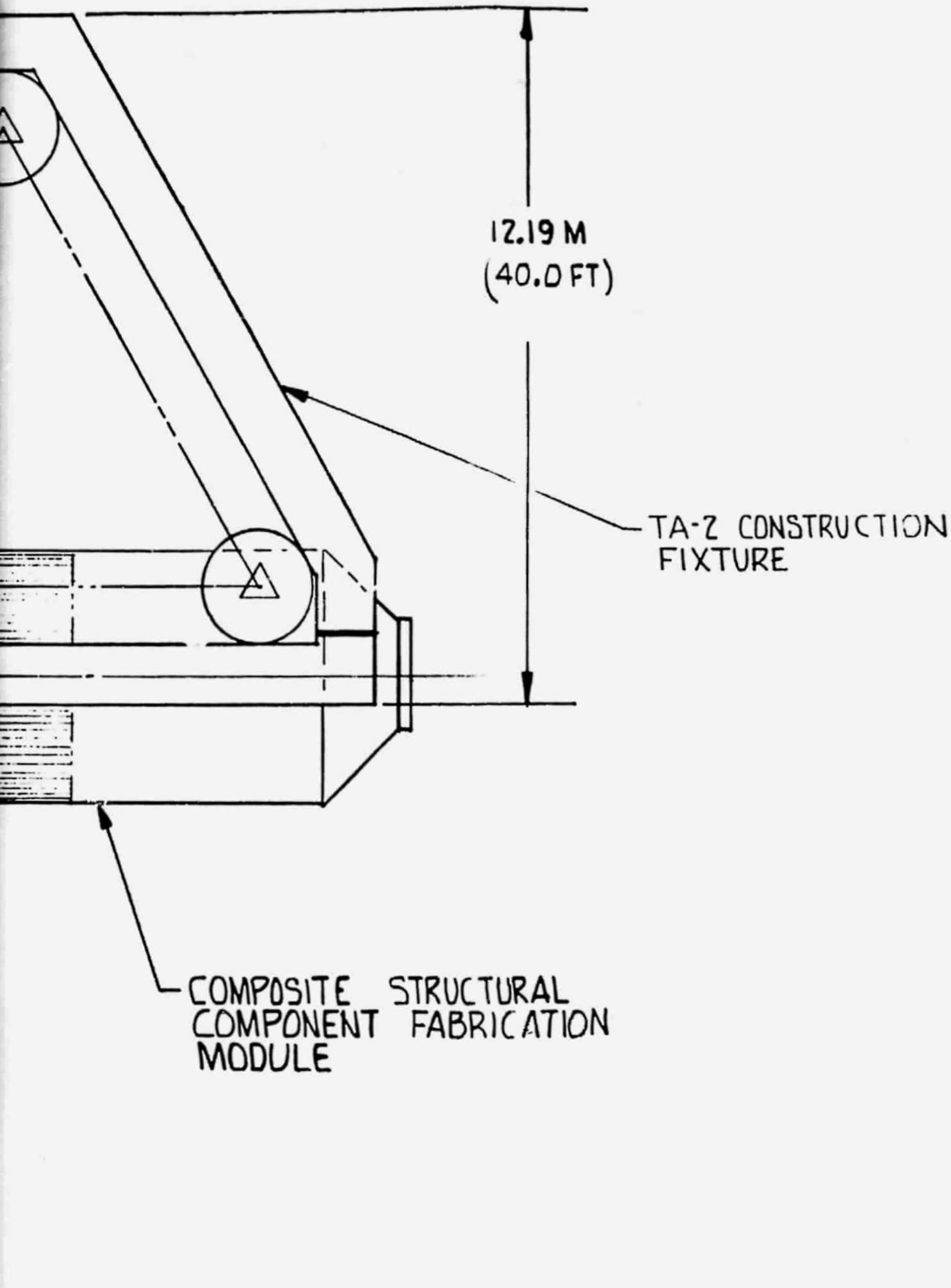

Figure 5-31. 7 Man SCB Configuration

crane. After verification, the initial manning crew then enters the SCB, the control center is activated, and all subsystems are brought on line and checked out. Approximately 180 days after core module launch, the initial logistics module is launched and berthed to one of the radial (Y-axis) ports. The logistics module stays with the cluster and acts as a supply center and emergency life support unit. At this time the SCB is fully assembled, activated, manned, and capable of initiating routine operations.

The resultant orbital configuration of the SCB, shown in Figure 5-32, consists of the core module, power module, space construction support module, crew support module, habitation/control module, and the initial logistics module. During the period of routine operations, the space processing modules are delivered and berthed to the radial berthing ports on the core module. Also, various jigs and fixtures of the Fabrication/Assembly facility are delivered and berthed to the SC support module.

- Core Module

The core module provides the basic module for berthing SCB habitation modules, power, logistics, space processing elements, and docking the entire cluster with the Orbiter. The core module is 4.41m (176 in) in diameter x 15.28m (50 ft) in length with eight radial passive berthing ports and two axial ports: one active and one passive. The module accommodates

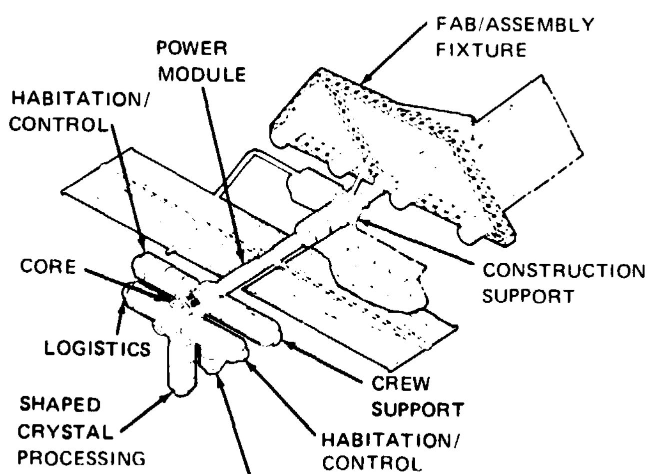

Figure 5-32. Option L Orbital Configuration

the primary power bus and conditioning equipment, initial power system, guidance and control system, RCS engine quads, coolant loops, and certain monitoring equipment to provide initial station buildup requirements. The core module is the main access route between cluster modules. Figure 5-33 represents candidate core module concepts. Functional requirements are the same as identified during the Phase-B study, with the exception of 180 hours emergency rescue system and incorporation of a complete thermal control system. The reduced diameter was investigated as means of transporting crane components, etc., packaged in a single launch. In the extended concept, a common diameter (4.41m) was selected with the reduced diameter (2.9m) and (3.9m) being too volume limited.

- Power Module

The power module incorporates a solar array of 1,067m^2 (12,500 ft^2) which delivers 34 kW power to the bus. The power module boom is 2.24m (88 in) in diameter x 15.84m (52 ft) in length, and houses the high-pressure storage

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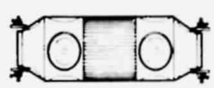
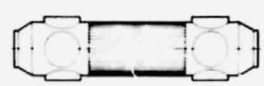
DESCRIPTION	PHASE B	EXTENDED VOLUME	EXTENDED VOLUME
			
PHYSICAL FEATURE			
LENGTH (M)	12.2	15.2	15.2
DIAMETER (M)	3.9	2.9	4.4
MASS (KG)	12,900	13,900	15,300
TOTAL VOLUME (M^3)	36	60	210
DOCKING/BERTHING PORTS	10	10	10
FUNCTIONAL REQUIREMENTS			
GUIDANCE & CONTROL	1	1	1
EVA AIRLOCK	1	1 (EMERGENCY) PALLET	1 (EMERGENCY) PALLET
REACTION CONTROL	1	1	1
INFORMATION	1	1	1
EPS(FUEL CELLS)	1	1	1

Figure 5-33. Core Module Options

tanks with appropriate control equipment. The module is normally pressurized, and the solar array orientation drives are maintainable in a shirtsleeve environment. Hatches are provided at each end of the module enabling the boom to become an emergency shelter. Figure 5-34 represents candidate power module concepts. Functional requirements are the same with the primary difference being the larger solar array which dictated a longer boom. An advantage of the extended length is the ability to berth directly to either end. A second-order advantage is the increased volume.

- Crew Support Module

The crew support module has a maximum diameter of 4.41m (176 in) and is 15.24m (50 ft) long. Externally, the module has two axial berthing ports (one active and one passive) and a full radiator/meteoroid shield. The interior of the module will contain the crew support facilities which include: galley, dining/recreation, ECLS, emergency control center and medical/exercise area.

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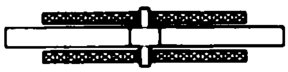
DESCRIPTION	PHASE B	EXTENDED VOLUME
		
PHYSICAL FEATURE		
LENGTH (M)	9.3	15.2
DIAMETER (M)	2.0	2.0
ARRAY AREA (M^2)	650	1,160
MASS (KG)	10,100	12,800
TOTAL VOL (M^3)	33	54
FUNCTIONAL REQUIREMENTS		
EPS GAS STOWAGE	1	1
REPRESSURIZATION GAS	1	1
SOLAR ARRAYS	1	1

Figure 5-34. Power Module Options

- Habitation/Control Module

The habitation/control module also has a maximum diameter of 4.41m (176 in) and a length of 15.24m (50 ft). Externally, the module is identical to the crew support module. The interior will contain a commander/executive-type stateroom and six crew staterooms. The crew accommodations will be arranged so that a mixed crew (male and female) can be accommodated. In addition to the crew quarters, the module contains two separate personal hygiene facilities, ECLS, the primary SCB control console and its associated electronics, and the second 180 hours energy rescue system.

- Space Construction Support Module

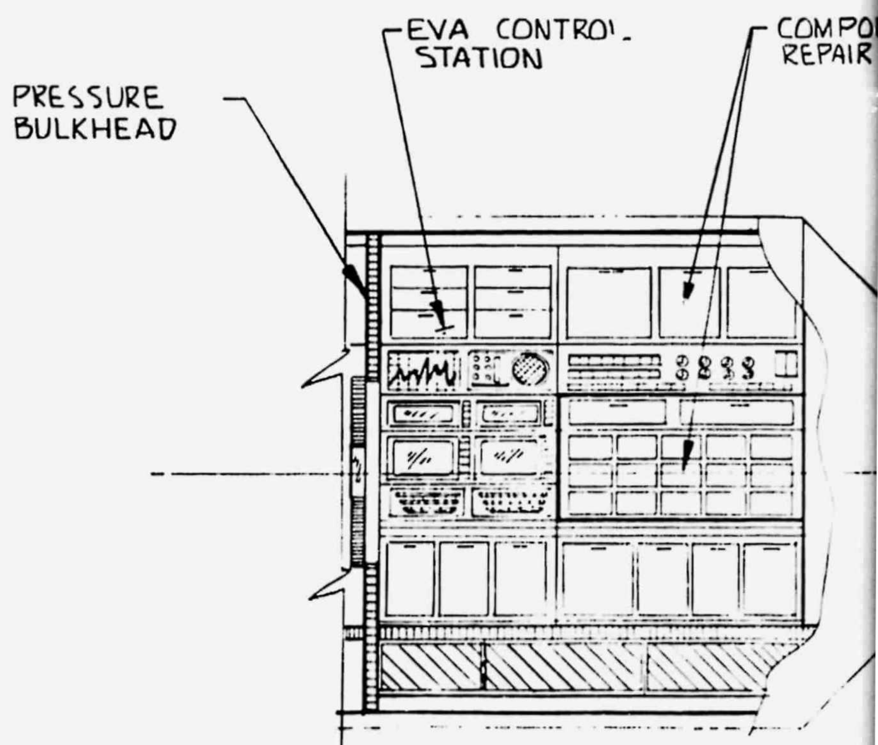
The space construction support module, shown in Figure 5-35, has a diameter of 4.41m (176 in) and is 15.24m (50 ft) in length. Externally, the module has two axial berthing ports (one active and one passive), four radially located passive berthing ports and a full radiator/meteoroid shield. The interior of the module emphasizes maximum usage for crane control, crew support, and EVA preparations with the majority of the fabrication being accomplished in the immediate vicinity of the module by attaching assembly jigs to the sides and aft of the module. Thus, the crane can transport material directly from the materials canister or pallet directly into the assembly fixture, or can supply raw material (metal stock or composite fibers) directly to the fabrication machines held by the assembly jigs. The EVA airlock section provides for a 4-man crew operation with backup gear for one additional man.

- Logistics Module

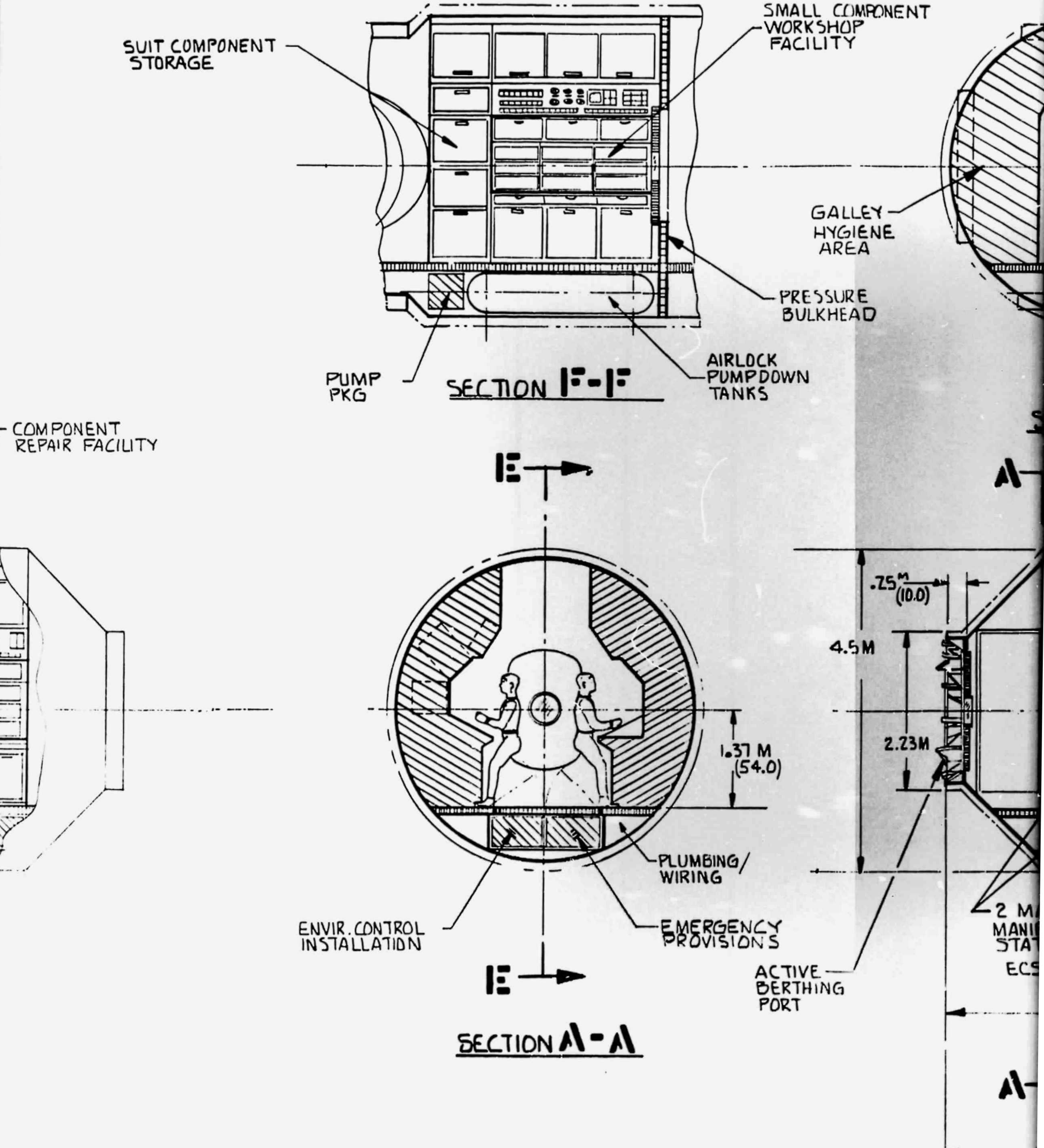
The logistics module is 4.41m (176 in) in diameter x 7.75m (25 ft) long. The interior will be configured to provide pressurized and unpressurized compartments as required for three basic functional requirements: (1) palletized (solid) cargo; (2) liquid/gas cargo; (3) special cargo. The logistics module can also be used as an emergency volume.

- Fabrication/Assembly Support Facility

The fabrication/assembly support facility is shown in Figure 5-36. The fundamental elements consist of the space construction support module, a two-arm crane, a composite-tube fabrication unit, a beam assembly fixture, and a solar collector fabrication and assembly fixture.



SECTION E-E



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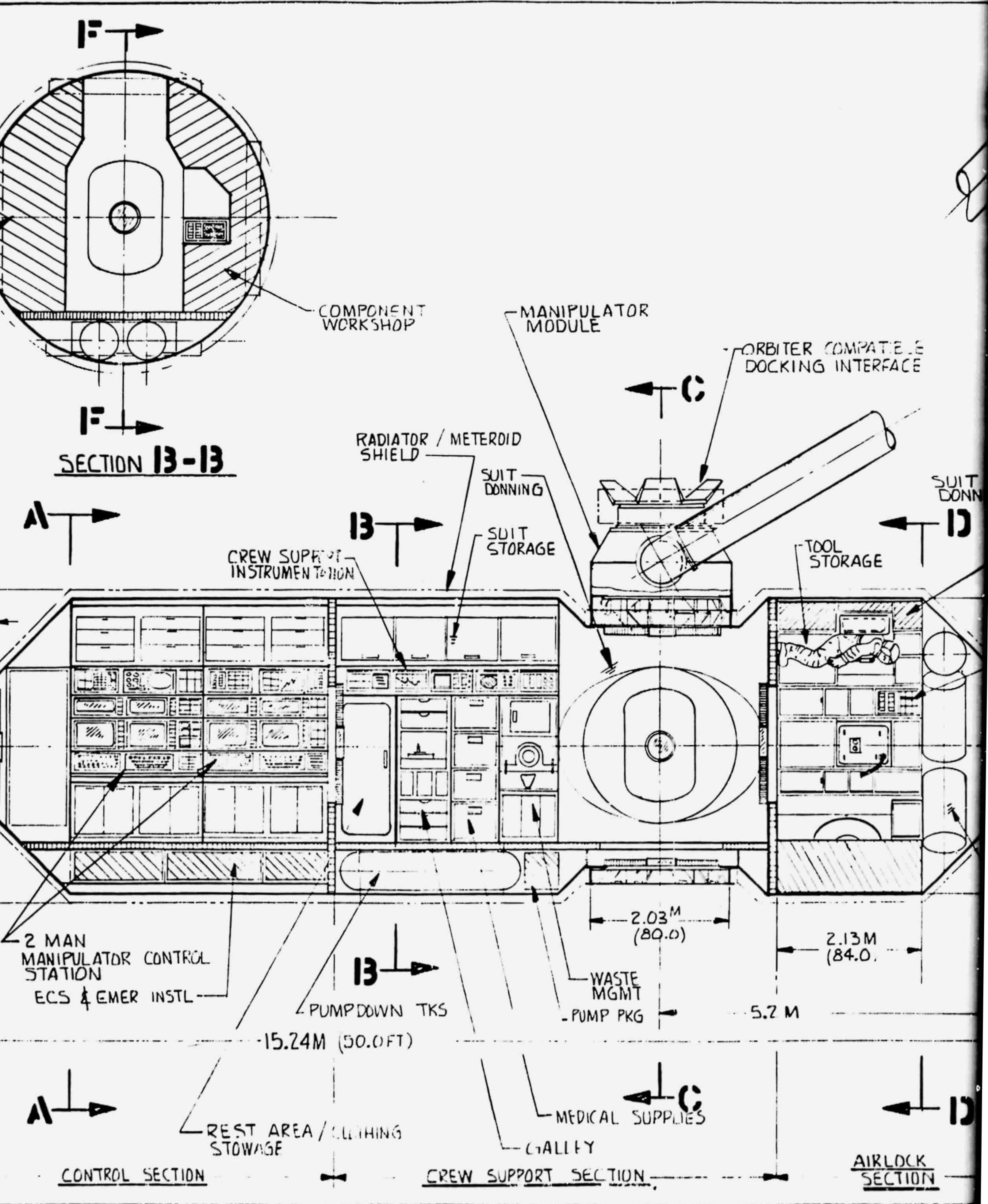
FOLDOUT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SECTION B-B
COMPONENT WORKSHOP
MANIPULATOR MODULE
ORBITER COMPATIBLE DOCKING INTERFACE
C
RADIATOR / METEROID SHIELD
SUIT DONNING
SUIT DONN
A
B
SUIT STORAGE
D
TOOL STORAGE
CREW SUPPORT INSTRUMENTATION
2.03M (80.0)
2.13M (84.0)
2 MAN MANIPULATOR CONTROL STATION
B
WASTE MGMT
ECS & EMER INSTL
PUMPDOWN TKS
PUMP PKG
5.2 M
15.24M (50.0FT)
A
C
D
MEDICAL SUPPLIES
REST AREA / CLOTHING STOWAGE
GALLEY
CONTROL SECTION
CREW SUPPORT SECTION
AIRLOCK SECTION

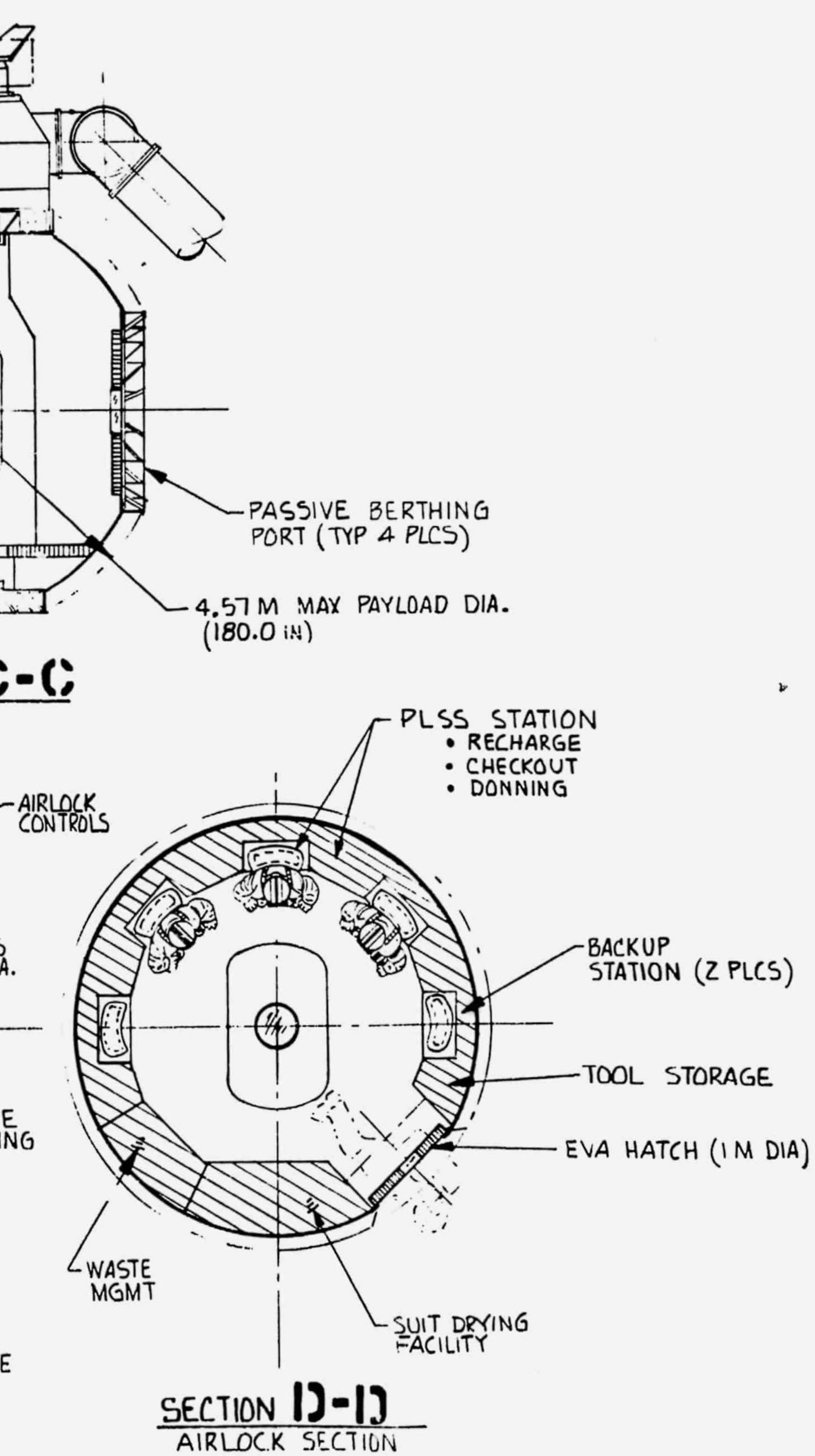

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Figure 5-35. Space Construction Support Module

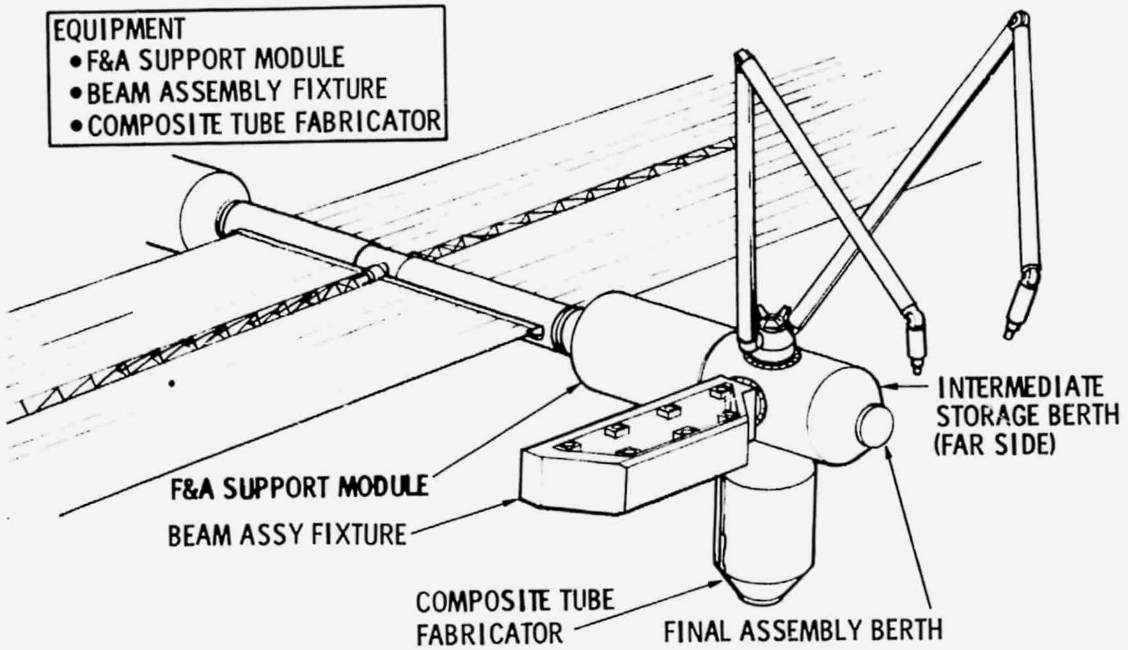

Figure 5-36. Fabrication and Assembly Support Configuration

The SC support module previously defined, contains the fabrication and assembly control statio; which monitors and controls all of the housekeeping functions of the SC facility as well as SC equipment and operations, a crew rest and hygiene facility, a 4-man EVA airlock with the EVA suits and support equipment.

The truss assembly jig provides the jigging (variable geometry) for prefabricated longerons. Beam assembly occurs by feeding the longerons through their holding devices and assembling cross struts to them in a linear beam buildup process. The cross struts are positioned and joined to the longeron by computer-programmed manipulator robots on the assembly jig structure.

The assembly jig is configured to build up beams having between one and five triangular bay sections.

The composite-tube fabrication unit contains the weaving machine, the curing furnace, and an appropriate collection of tube-shaped mandrels for fabricating the various tubes in the baseline objective element program.

A two-arm maniuplator crane provides the control, movement, and dexterity needed in the buildup process of the objective elements. The crane arms provide a reach of approximately 35m from the berthing port where the crane module is located.

The remaining lateral berthing port would be reserved for logistics modules, while the axial end port would be used for the objective element buildup or final assembly.

The collector assembly jig is built up on the longitudinal (X-axis) end port of the fabrication and assembly support module. The collector assembly jig is built up from prefabricated sections which are logistically supplied to the SCB. The assembly jig is oriented so that the solar cell array active surface faces toward the horizon (Y-axis) during construction. The north-/ or south- facing selection is determined by the specific orbit which will preclude direct solar illumination of the solar cells and resultant power generation during the construction. The construction orientation is a compromise between minimum solar and earth illumination of the cells and a goal of uniform thermal illumination for control of the collector geometry.

The assembly jig includes six modules which contain the roll forming and joining equipment to fabricate the collector longerons in-situ. Prefabricated struts are removed from a logistics module for installation in the collector assembly.

5.3.7 Subsystem Analysis and Preliminary Trade Studies

Five major subsystems were examined in light of (1) data available from the JSC Phase-B Space Station Definition, and (2) data available from other sources including information on Orbiter subsystems. The results of these analyses are included in the following paragraphs.

5.3.7.1 ECLSS Considerations

The Part 2 study activity in the area of ECLSS consisted of (1) determination of ECLSS design drivers, (2) synthesis of a near-optimum preliminary design for the various program options, and (3) generation of the basic characteristics of each program option design. Only a brief summary of the activity will be presented here, whereas Volume 3, Book 2 gives a detailed description of results.

Two basic program approaches were addressed, i.e., the permanently manned (1) option and the Shuttle-tended (L') option. Several levels of Shuttle dependency were considered in the Shuttle-tended mode. A single concept was developed for permanently manned configurations. This single concept is near optimum from a cost standpoint for most LEO and GEO applications. The conclusion was reached upon review of past system studies and trades and by taking into consideration the current state of the art. Concepts were favored which are currently being developed because of the substantial nonrecurring cost savings to be realized. Concepts selected were basically those identified in the previous Phase B Modular Space Station studies. Minor modifications were made to reflect unique SSSAS requirements and results of the NASA/JSC-funded study called "Regenerative Life Support Evaluation (RLSE)." The selected concept consists of a closed water loop and a semiclosed oxygen loop. Water electrolysis is used to produce 0_2 and H_2 for ECLSS needs and also for propellant for the RCS . A mass balance of this concept results in a slight excess in water because about half of the crew food intake contains water.

A detailed survey was made of Shuttle ECLSS resources available to support a Shuttle-tended SCB. It was found that sufficient resources are available to provide ample support of an SCB manned to five men or less. The only possible systems required by the SCB would be a separate active cooling loop to cool SCB coldplated equipment, a cabin heat exchanger to cool air, and a small fan/ducting to direct ARC air from the Orbiter. If solar cells become the power source, some means of water recovery may be considered.

Earlier versions of the SCB would use fewer resources, and the initial habitable volume may use only atmosphere control and air revitalization.

5.3.7.2 Communications Subsystem Analysis

Communications requirements and characteristics of the Phase B subsystem design were reviewed and their applicability to a permanently manned SCB analysed during Part 2. The use of Orbiter equipment for performance of the SCB communications functions was also reviewed. It was found that the capability embodied in the Orbiter S and Ku-band transponders and signal processors were in excess of requirements.

A review of Phase B communications subsystem revealed that this earlier requirement was somewhat outmoded because direct transfer data rates were identical to those provided at Ku-band via relay satellite. The present philosophy is that remote sites will be used for backup purposes; primary data transfer and tracking will be performed via the tracking and data relay satellite (TDRS).

The TDRS data rate of 50 Mbps was found to be far in excess of scientific data transfer requirements although the SCB may actually require this rate for radiometry data. The Phase B subsystem data transfer rate of 500 Kbps must be questioned since the on-board checkout system should obviate the necessity for transfer and storage of large amounts of essentially useless data. The backup VHF capability which was originally assumed in the TDRS has been superceded by the S-band capability.

UHF voice and telemetry transmission has also superceded the previous VHF requirement for EVA operations. Voice system performance using 32 Kbps voice signal encoding on the S and Ku-band systems should be far superior to the analog concept which was employed in the Phase B design.

Two areas in which Orbiter equipment is not suitable include the 300 Hz to 10,000 Hz entertainment uplink and the reproduction of graphic data via facsimile. While the loss of the capability may be somewhat detrimental to operations, the capability may be partially offset by graphic transmission via the Ku-band/Mbps uplink. Its use in conjunction with the multifunction CRT display system would allow simple diagrams to be reproduced.

In summary, it has been found that no additional communications subsystems are required to supplement those available from the Orbiter. It may, of course, be advantageous to employ additional switching and antenna units to compensate for antenna beam blockage by SCB modules. It may also be desirable to reprogram network and Ku-band signal processor base band structures should different rate or bandwidth requirements eventually be defined.

5.3.7.3 Data Management Subsystem Analysis

A review was made of the Phase B data management subsystem (DMS) design requirements, performance characteristics, and the tradeoffs

pertinent to the selection of the overall subsystem design. The requirements were then contrasted with the general requirements for SCB support in the data management area. The feasibility of implementing the subsystem with available Orbiter or Spacelab components was also investigated.

The design requirements for the DMS design were found to be somewhat awesome (7 million equivalent adds per second (EAPS) for power management as indicated by Volume IV of the Information Management Advanced Development Final Report) and a basic philosophy change will be required in subsystem support if Orbiter components are to be considered. However, the basic driver functions appear to be applicable to the permanently manned SCB as is the distributed processing design philosophy.

The Phase B Space Station DMS design essentially employed a multiprocessor containing two arithmetic units and a plated-wire operating memory. The system was sized to perform 1000K EAPS based upon an initial design requirement of 1262K EAPS assuming a growth margin of 100%. The operating memory contained 134K 32-bit words, the mass memory contained 682K words, and the archive memory 8.5M words, using the same growth margin. A data bus operating at 10 Mbps interfaced with other station subsystems via a remote acquisition and control unit (RACU). Processing functions performed by the system in addition to subsystems support included operations management, on-board checkout management, and G&C preprocessor management; i.e., its functions did not include local processing. A rather large central executive overhead of 15% (82.3 EAPS) without growth considerations was allocated due to the nature of the system. Preprocessors were employed to perform repetitive tasks within certain subsystems.

With the advances in microprocessor design and their off-the-shelf availability, a much larger portion of the processing tasks may be relegated to the preprocessors. The role of the central processor then becomes one of preprocessor and file management allowing the use of the AP-101 Orbiter computer and the 1-Mbps data bus rate as implemented by the multiplex interface adapter assemblies (MIA) and multiplexer/demultiplexers (MDM). Orbiter mass memory units may be employed for program storage while archiving may be performed on the ground and programs transferred via the uplink. Therefore, it is considered feasible to use Orbiter components to perform the SCB processing tasks. This assumes that the magnitude of

these SCB tasks will be much reduced from that previously estimated. One additional function not previously performed has been added, that of crane control for the SCB. The impact on the central system is considered negligible since the operating rate of 100K EAPS would be met by a dedicated preprocessor.

5.3.7.4 Electrical Power Subsystem Analysis

The Electrical Power Subsystem (EPS) requirements and characteristics of the Phase B subsystem design were reviewed and the applicability to a permanently manned SCB evaluated. The EPS generates, stores, regulates, controls, conditions, and distributes the electrical power required by the SCB.

A summary of the requirements and characteristics of the EPS for the various Option L SCB systems is presented in Table 5-16, along with a summary of the Phase B system for comparative purposes. The three

Table 5-16

EPS REQUIREMENTS AND CHARACTERISTICS - OPTION L AND PHASE B

		Option L - Permanently Manned		
	Rockwell Phase B (ISS)	Direct Growth L 7-Men	14-Men	Unconstrained 21-Men
Number of Men	6	7	7→14	21
Electrical Power Reqm't *kWe	19.6	23→37	55	80
Power Output Capability, kWe				
• Bus (EOL-5-years)	19.6	34	68***	68***
• Array (EOL-5-years**)	47	81.5	163	163
• Array (BOL**)	66.5	105	210	210
Solar Array Area, M^2 (K ft^2)	651 (7.0)	1,162 (12.5)	2,330 (25.0)	2,330 (25.0)

* Load bus, 24 hour average
** At 80°C
*** Two power modules at 34 kWe each

Option L- permanently manned system options are: (1) direct growth L, 7 men, (2) 7 men with growth to 14 men, and (3) unconstrained 21 men. The second row of the table presents the average electrical power requirement at the load buses. The direct growth 7-man requirement is initially 20-23 kWe for the first seven years of the mission, at which time it grows to 37 kWe (the load buildup with time for this and the other system options discussed here is presented in Volume 3, Book 2.

The load bus power output capability designed into the various SCB's generally approximates the requirement; the differences stem from the fact that the maximum-capability power module that can be delivered in a single Shuttle is 34 kWe. Consequently, the 7-man and 21-man SCB's use either one or two of the 34-kWe power modules. It is expected that refined objective element program scheduling can reduce the power requirements to the output capabilities shown. The two modules provide excess capability in the case of the 14-man SCB.

The SCB EPS employs the same principles as the Phase B system. Primary electrical services are provided by a 2-degree-of-freedom solar array. Power during eclipse periods is provided by fuel cells operating from a stored reactant supply, which is generated by water electrolysis during sunlight periods.

A comparison of the SCB and Phase B power module configurations has been presented previously. The beginning-of-life (BOL) solar array areas are based on current SEPS projections for array performance at LEO and the expected 5-year degradation in a 400km, 28.5° orbit.

A cursory evaluation of the utility of Shuttle components indicates that the Orbiter fuel cell is applicable to the fuel cell/electrolysis energy storage concept assumed for SCB.

5.3.7.5 Guidance, Control, and Navigation Subsystem Analysis

The Guidance, Control and Navigation Subsystem (GC&NS) analysis activity during Part 2 consisted of in addition to a review of the JSC Phase B design, (1) generation of general requirements, and (2) preliminary conceptual GC&NS designs for the Program Option L and L' configurations. A summary of study findings is presented here; further details are available in the GC&NS and orientation study appendices in Volume 3, Book 2.

Two basic program approaches were addressed, i.e., the permanently manned (L) option and the Shuttle-tended (L') option. The Option L GC&NS design was derived from the Phase B design with changes defined where SCB design requirements rendered the Phase B design inappropriate. Since only general SCB design requirements were available, only minor modifications to the Phase B design were proposed.

Further investigation is required in the area of objective element construction and testing requirements relative to the GC&NS. Also, much study of the dynamic interactions of the GC&NS with the crane operations and flexible structure is needed. Large gravity-gradient torques are possible with the Options L and L' configurations and major RCS propellant/CMG mass impact may result if adverse orientation requirements surface.

Growth to larger SCB configurations do not represent potential major impacts to the GC&NS except in the area of aerodynamic drag makeup propellant and disturbing torque control. Disturbance torques related to configuration are a strong function of principal moments of inertia axis-to-axis differentials and adverse combinations of orientation and SCB mass properties could result in major impact to the GC&NS.

5.3.8 Space Processing Approaches

The systems engineering approach used to gain an understanding of the impact of space processing requirements on the SCB design used three case studies. They were carefully selected and centered around the commercialization of three types of products in space: (1) biological or pharmaceutical-class materials, (2) ultrapure glasses, and (3) shaped crystals. Additional information concerning the application and commercial interest in these materials can be found in the SSSAS Part 1 Final Report, Volume 3, Book 1.

The three cases studied provided a requirements base from which conceptual configurations of the mission hardware modules could be developed. These concepts in turn could be used to assess the SCB design drivers. The systematic selection of the product prototypes during Part 1 of the study was made after consideration of the following factors: (1) reasonable expectation of a

commercial market for the product if developed, (2) sufficient scientific evidence or theoretical basis for probability of successful development (subjective assessment arrived at by experts in related fields), and (3) description of the range and extent of SCB/mission hardware requirement across the product spectrum. In summary, the space processing design drivers include the following:

1. Disturbance-free environment requirements (10^{-3}g).
2. Long-term processes, up to 90-day duration.
3. Bioisolation requirements.
4. Living matter handling and environmental controls.
5. Batch and continuous operations processing.
6. Levitation furnace.
7. Average power levels of 25 kW and greater.
8. High power peak levels (>100 kW) for production growth.
9. Hazardous material safety.

Table 5-17 lists four classes of distinguishing characteristics that modules dedicated to the space processing of the three types of products require. These requirements were the result of reviewing the description of the process as defined by the case studies. Details of the process flows, equipment requirements, and other pertinent data can be found in Volume 3, Books 1 and 2 of this report. In addition to the basic processing equipment required to perform the basic production process which would be developed and optimized in a dedicated module, the ancillary equipment and working space for crew preparation (i.e., decontamination) and analytic support are included. Overall estimates of the dedicated modules' dimenions, weight, and electrical power demand are shown in the table.

Figure 5-37 is a visualization of the interior configuration of the dedicated bioprocessing module. The four-section module would be entered from the left. The first compartment, labeled Crew Preparation Section, would serve as an overall control station for the module and provide office space for the commercially oriented operations. The next compartment, labeled Decontamination Section, would contain the washdown facilities, garment sterilization, and storage provisions.

Table 5-17

MODULE CHARACTERISTICS

Distinguishing Characteristics	Dedicated Space Processing Modules: Biologicals	Ultrapure Glasses	Shaped Crystals
Physical			
Dimensions (m)	11.7 x 4.26 D	11.7 x 4.26 D	15 x 4.26 D
Weight (kg)	11,500	14,500	14,500
Average power (kW)	4	20	12
Peak power (kw)	8	30	18.5
Volume (m^3)	175	175	222
(Equipment)	(112)	(112)	(142)
(Working)	(63)	(63	(80)
Operational			
Common to all:	3-man crew	4-man crew	3-man crew
• Autonomous/ • Production dedicated	Batch process operations	Batch process operations	Continuous operations
• Complete access to equipment • Centralized controls			
Functional			
Common to all: • Use SCB subsystems • Add subsystem capabilities as required	Separate ECS for each compartment processing compartment Bioisolation	Thermal control loops Emergency isolation of processing compartment	Access to space vacuum Emergency isolation of processing compartment
Configurational			
Number of compartments	4	2	2
Processor Location	Center aisle plus bays	Center aisle	Center aisle plus bays
Analytic station	In separate compartment	In processing compartment	In processing compartment
Crew decontamination	Yes	No	No
Office space	Yes	Yes	Yes

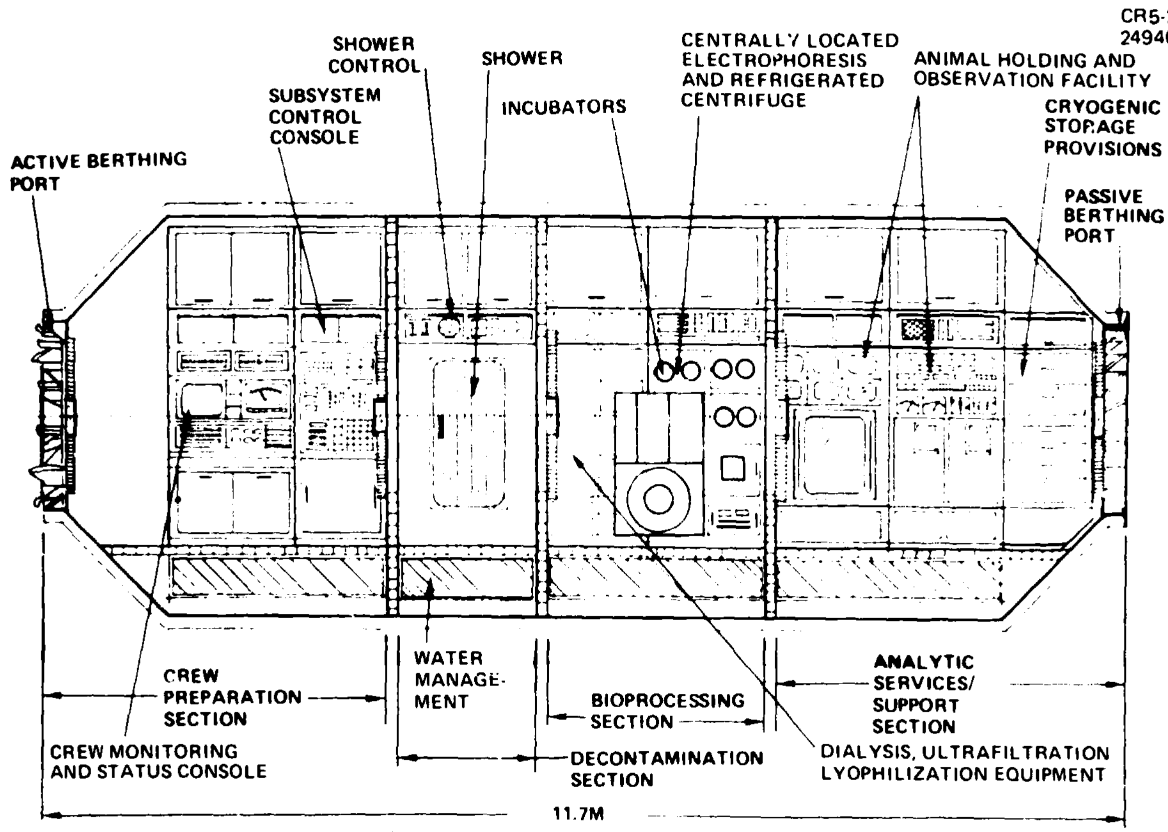

Figure 5-37. Biologicals Processing Module

The Bioprocessing Section would contain the equipment required to implement the production of the biological materials. This section of the module would maintain a controlled atmosphere at 3°C to protect the sensitive protein materials involved in the process. The basic processing equipment is shown centrally located to facilitate access to the apparatus for maintenance. The incubators needed for cell growth and enzyme production are shown cabinet-mounted, along with other bioprocessing equipment. The cabinets feature pullout capability for access to components mounted in the back.

The Analytic Services/Support Section, shown at the right of the figure, is equipped with instruments for microscopic examination, chemical evaluation, and bioassay testing with live animals. These functions are required to support production in terms of product determination, characterization, and quality assurance, as well as similar analysis of the working solutions, bases, and nutrient materials involved in the bioprocessing. The analytic

capability represented by this compartment, which find counterparts in the other two processing modules, is essential to the process development and optimization operations. Also included in the module are provisions for storage of materials, equipment and supplies, communications terminals, and a TV camera with ground-controlled focus and scan to comply with FDA requirements.

Figure 5-38 shows the module for processing of ultrapure glasses. The two-compartment module would provide accommodations for the processing furnaces, analytic instruments required for product inspection and characterization, process and module controls and displays, and space for storage and office space. An important feature of the module is the work bench on which is mounted the four furnaces used in the glass forming, shaping, cladding, and annealing. The work bench is centrally located to permit access to the furnaces and to the equipment needed for adjustments and modifications.

Figure 5-39 is a representation of the two-compartment Shaped-Crystal Processing module. Entry to the SCB in the view presented in the figure would be to the left through the Crew Support Section. The processing to the left of the pressure bulkhead accommodates the silicon ribbon processor, solar cell assembly processor, and the necessary controls and displavs associated with the processors. Also in this compartment are the analytic instruments required for off-line product characterization procedures. The procedures would support production process development and optimization activities.

As noted in the objective elements definition and program descriptions given earlier, objective elements were selected for Part 2 detail conceptual definition. These were selected on the basis of early potential and applicability to the initial program time frame of 1984 to 1987. The seven objective elements were defined to provide detailed support requirements to be imposed on the space construction base in each of the program options. This work was accomplished in Task 4.1. This approach permitted a realistic analysis and conceptual design of the space construction base to be accomplished which can be presented and substantiated as a practical system option.

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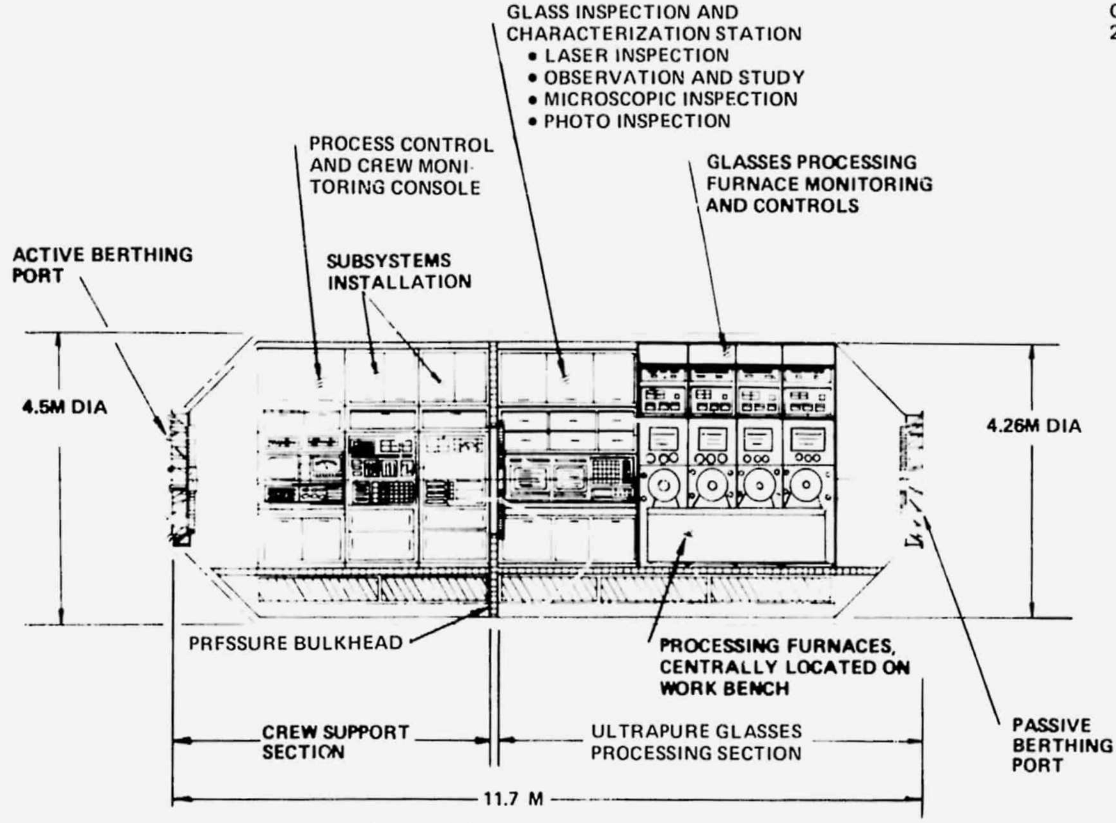

Figure 5-38. Ultrapure Glasses Processing Module

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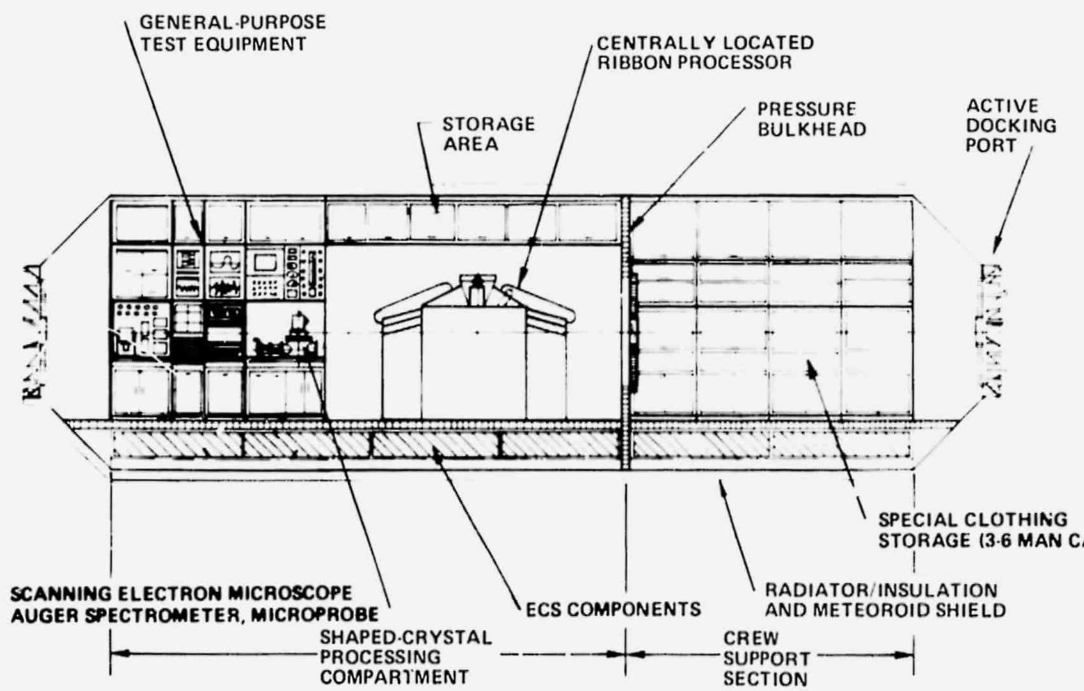

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Figure 5-39. Shaped-Crystal Processing Module

This objective category identifies high power requirements in the space development of ultrapure glasses and shaped crystals. It requires appropriate scheduling of these objective elements in Program Option L to maintain total bus power at a level compatible with a single power module (i.e., an approximate 35 kW at end of life). The noted power levels include all power requirements for the space processing modules. Crew requirements shown are fully dedicated crewmen for the duration of the space processing development phases.

5.4 LOW-COST MODULE STUDY

The objective of this portion of the study was to determine how much influence the selected structural design had on the cost of a Space Station module and to identify low-cost structural approaches. Design layouts were prepared for a module using simple monocoque skins for comparison with one using machined isogrid skins. The layouts are shown in the discussion of the low-cost module study in Volume 3, Book 2. They were used to develop manufacturing plans and to derive materials and manufacturing costs. In addition to the costs derived for the monocoque and machined skin approaches, three options were compared for attaching the frames and longerons required to distribute the launch reactions with the monocoque design. These were welding, huckbolting, and weldbonding.

The cost of the structural subsystem is a small part of the total Space Station module cost. The structure represented 6.7% of the total cost in the MDAC Phase B modular Space Station cost breakdown. The cost of equipment installation, integration, and checkout is a much more significant proportion of the total cost, and is a strong function of accessibility. The cost difference between bolted and welded joints for joining the end bulkheads and pressure-shell cylinder was derived to assess the cost of providing maximum accessibility. With the monocoque cylinder, the bolted-end bulkhead joint adds $15,520 to the module cost, largely because of the cost of the two machined roll ring forgings required for the bolting flanges. The bolted joint adds very little to the cost of the isogrid cylinder because the integral end flanges add nothing to the materials cost, and the increase in machining costs that the bolt well pockets produce is offset by the two added circumferential welds required with the welded-end bulkhead joints. But even with the monocoque

cylinder, the added cost of the bolted bulkhead joint appears small compared with the potential savings in installation costs because of the improved access the removable end bulkhead makes possible.

5.4.1 Structural Costs

The cost of engineering, manufacturing, and materials for the cylinder configurations are summarized in Table 5-18. In addition to the cost for design layouts, analysis, and production drawings, the engineering estimate includes the system costs for sustaining engineering and liaison.

The materials and manufacturing costs for the monocoque cylinder have been updated to reflect the substitution of stretch-formed extrusions for machined-ring forgings for the three frames required to distribute the launch loads with the monocoque skins.

5.4.2 Summary and Conclusions

As indicated by the results summarized in Table 5-15, structural cost cannot be used as the criteria for choosing between the isogrid and monocoque cylinder configurations. The difference in cost is within the accuracy of the engineering estimates alone. Alternative criteria must be reviewed to determine the superior approach.

The isogrid design provides a weight savings of about 1500 lb and eliminates huckbolt penetrations of the pressure shell. The monocoque skins provide improved radiation and meteoroid shielding. Both configurations are compatible with installation of the complete complement of equipment as an integrated unit, or in individual racks, the preferred choice depending on the equipment inventory for a particular mode.

From MDAC manufacturing experience on Saturn and current experience with Delta, coupled with the in-house design and analysis capability exercised for the external tank proposal, the isogrid cylinder is preferred. Another company, without this background experience, would, in all probability, prefer the monocoque configuration. Both appear to present equally viable low-cost approaches for the Space Station module.

Table 5-18

STRUCTURAL COSTS OF MODULE CYLINDER WITH BOLT-ON BULKHEAD OPTION

	Isogrid	Monocoque
ENGINEERING		
Layouts	$250,250	$311,500
Analysis	Parts Count 8	Parts Count 16
Production Drawings	(8 production drawings plus 4 layouts)	(16 production drawings plus 6 layouts
Sust. Engineering (Liaison and Changes)		
PRODUCTION (Average Unit Cost Based on Run of 6)		
Manufacturing	$177,101	$125,155
Materials	73,690	63,773
	$501,041*	$500,428*

*Does not include end bulkheads or secondary structure.

Section 6

OPTIONS G AND LG, AND ASSOCIATED TRANSPORTATION CONSIDERATIONS

Even though major emphasis was placed in Part 2 on the analysis of the low earth orbit options, program options that involved geosynchronous operations were investigated further in regard to two issues: (1) the comparative effects on the options of where the geosynchronous-bound large objective elements would be constructed (i.e. LEO vs GEO), and (2) the impact of these program options on transportation requirements -- especially the Orbit Transfer Vehicle (OTV).

Options LG1 and LG2 were analyzed to get at the first issue and are defined previously in Figures 2-4 and Figure 2-5. All four options were analyzed to assess the second issue.

Both LG1 and LG2 include geosynchronous accomplishments that evolve from initial capabilities established in LEO. The LEO SCB capability is the common base for these two options. Options LG1 and LG2 accomplish the same objectives with the geosynchronous-bound objective elements construction being accomplished in LEO for LG1 and at GEO for LG2.

In LG1, the objective elements are fabricated and/or assembled in LEO. Once constructed in LEO the elements are transported to GEO for test and operations.

In contrast to LG1, for LG2 the GEO objective elements are transported to geosynchronous orbit and constructed there. Test and operations would follow. Thus, the difference between LG1 and LG2 is the location at which the GEO objectives are constructed.

Program Option G consists of all geosynchronous options that accomplish the five objectives shown previously in Figure 2-7. Two modes of this option were analyzed, with G involving the early establishment of a permanent SCB

at GEO. A variant of the all-GEO option G was established as G' which provides a permanently manned SCB at a later time than G and is preceded by OTV - supported sortie missions. The TA-1 objective element would not begin until the permanent SCB is established, while the other four can begin at the outset.

The physical characteristics of the objective elements are discussed in Section 3. The major sizing characteristics of program options LG1, LG2, G and G' (crew, power, and Shuttle flights required) are shown in Figures 6-1, 6-2 and 6-3, respectively. A summary comparison is shown in Table 6-1. There is a wide variation in crew size, power, and Shuttle flight requirements. Note that LG2 requires 14 men at GEO since construction is performed there. The power and Shuttle flights needed are also noted to increase over LG1. Options G and G' have only geosynchronous activity and require up to 12 men. G' has an early 5-man sortie mode preceding the permanent SCB operation. The large number of flights needed for G' is to support this sortie mode of operation.

The major difference between Options LG1 and LG2 is the location of the site of objective element construction — LEO or GEO. A study was accomplished to examine the effect of construction site selection on system cost. The seven major issues relating to the choice of construction site, culled from the total evaluated are shown in Table 6-2. The potential system impacts are also shown. The remaining issues found not to have a great influence were: boost loads, thermal stresses, test procedures, number of men in orbit, time to accomplish objectives, and transit time to GEO.

6.1 SCB ELEMENTS

The SCB elements needed for LG1 and LG2 differ because of the orbit location of the main construction task., i.e., the construction of the GEO-bound objective elements. The left portion of Figure 6-4 shows the LEO and GEO facilities needed to support LG1. The LEO portion is shown at the 14-man level (it grows to a total of 36 men), while the GEO station is shown at its full complement of 4 men. The LEO facility is outfitted to support the space processing objectives and all the LEO objectives, while constructing the GEO-bound objective elements. (The SPS array fabrication and assembly unit is shown attached.) The GEO facility is configured to support the test of the GEO elements after they are transported intact from LEO.

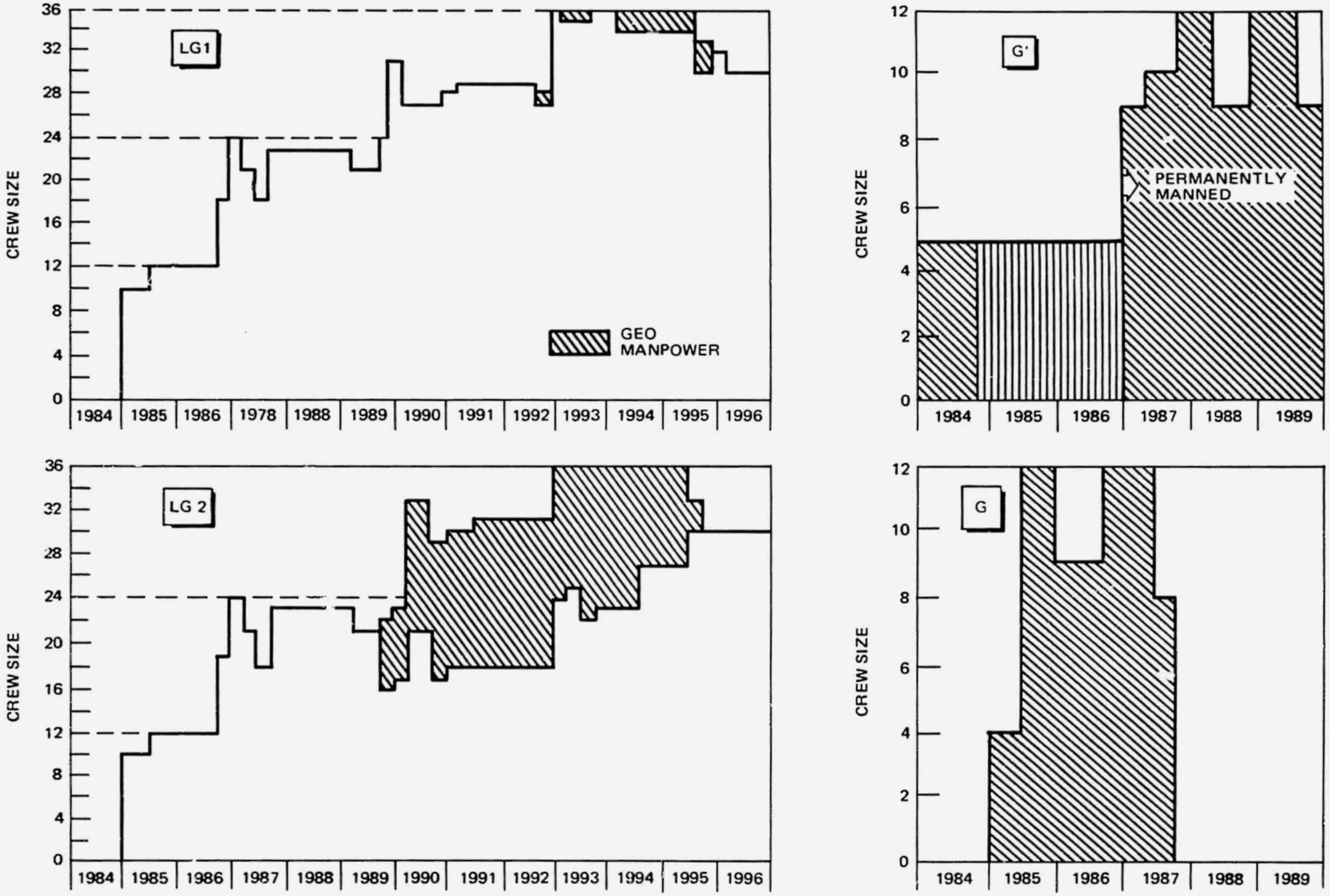

Figure 6-1. Crew Size Requirements

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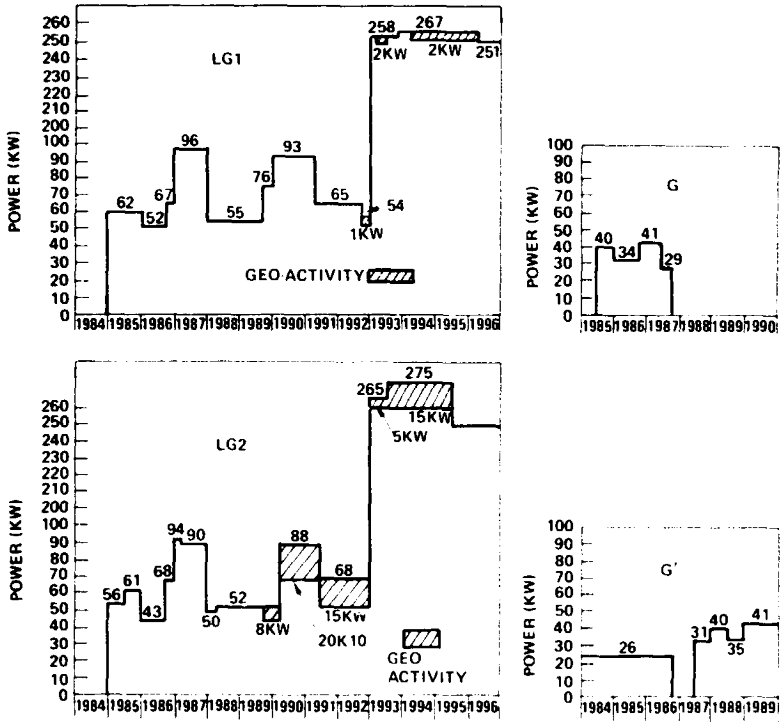

Figure 6-2. Power Requirements

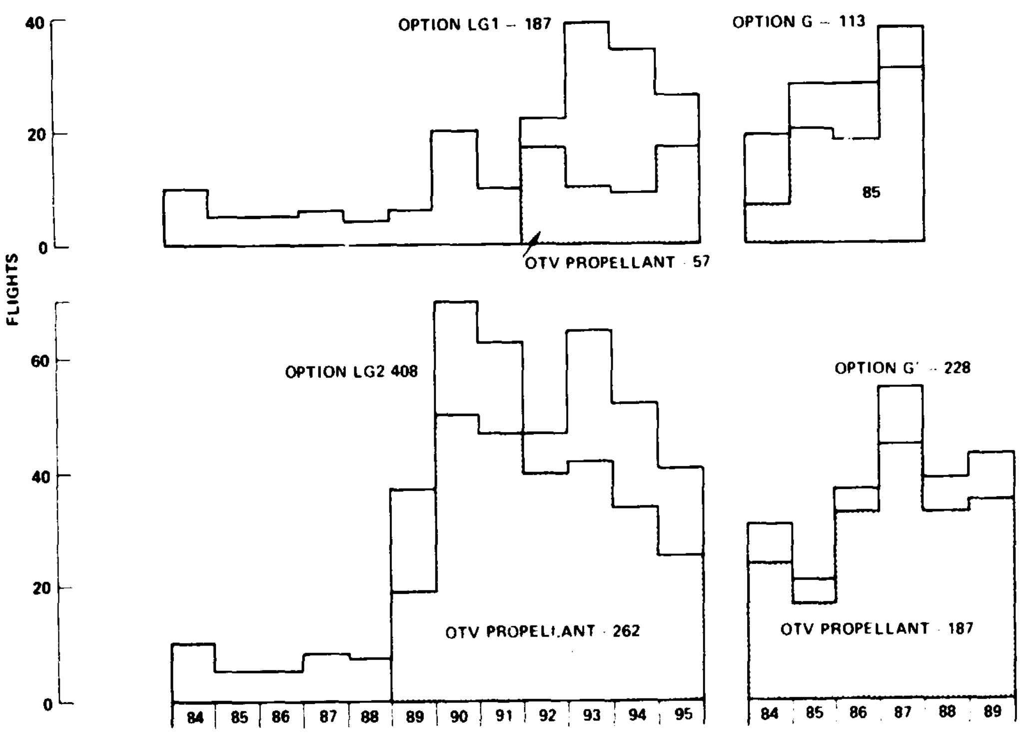

Figure 6-3. Shuttle Flight Requirements

Table 6-1

OPTION LG AND G SIZING CHARACTERISTICS

	Program Option			
	LG1	LG2	G	G'
Crew Size				
LEO	12 to 36	12 to 30	-	-
GEO	4	14	12	
Power (kW)				
LEO	50 to 270	50 to 270	-	-
GEO	2	15	30 to 40	25 to 40
Shuttle Flights	187	408	113	228

Table 6-2

MAJOR LEO VS GEO CONSTRUCTION ISSUES

Issue	Major Impacts
SCB system elements	No. elements, cost
Transportation requirements	No. flights, growth Shuttle, OTV size
Transfer to GEO	System complexity
Orbit keeping	Mission hardware weight SCB propulsion
Orbital forces and moments	Control system design
Plasma interactions	Mission hardware design/operations
Radiation	EVA suit, biowell

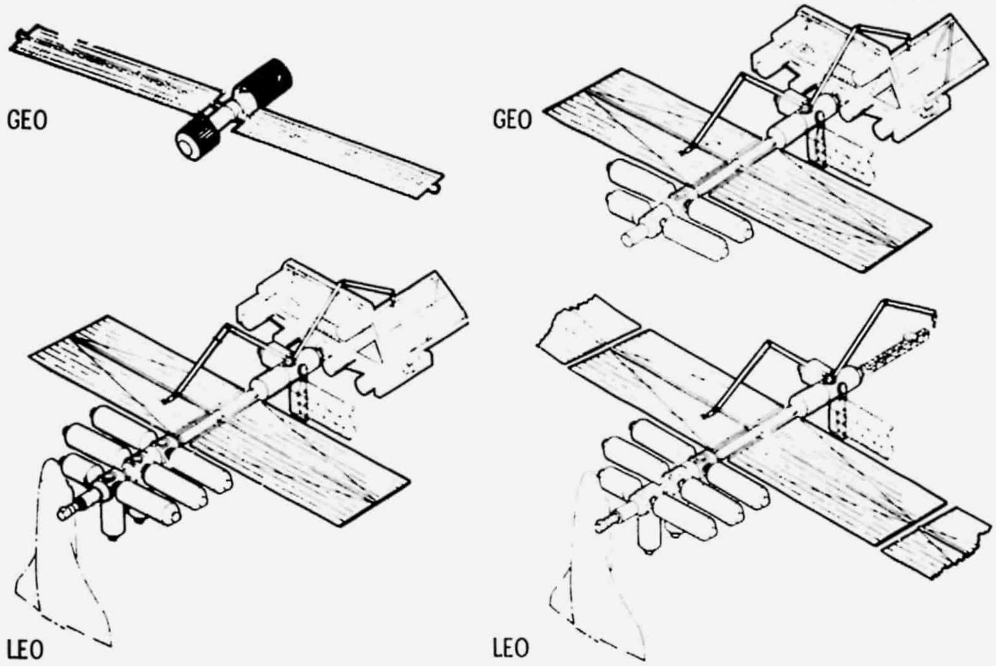

Figure 6-4. SCB Elements – LEO vs GEO Construction

The right portion of Figure 6-4 shows the corresponding SCB elements needed at LEO and GEO for Option LG2. At LEO, only the LEO objectives are supported. These include space processing, a 100 and 300m radiometer, et al. At GEO the SCB consists of a 12-man crew and the fabrication and assembly tool for construction of the GEO objective elements. The crew size needed at LEO, shown at 14 men, grows to 30.

A time-phased comparison shows that more SCB modules are needed for Option LG2 (the GEO construction option) than for LG1 (the LEO construction option). The difference is seven modules and they are needed earlier. The options could be scheduled differently to reduce this total but the LG2 option would take longer. Thus, it appears that LEO construction has the advantage of requiring a lower number of modules as compared with GEO construction.

6.2 TRANSPORT REQUIREMENTS TO LOW EARTH ORBIT

The transportation requirements to LEO were calculated to measure the differences caused by LG1 and LG2 construction sites. The left portion of Figure 6-5 shows that the objective element material lifted is the same. More Space Station elements are needed for LG2 (the GEO construction case) to support construction at GEO. The major difference lies in the OTV propellant needed. Most of the propellant difference is due to the increased crew activity at geosynchronous for Option LG2. Additional OTV propellant is also needed to transport an SCB and the material to construct the objective elements to GEO. For LG1, with construction at LEO, the major item SPS (TA-3) can be self-powered to GEO using its sclar array, thus reducing the OTV flights and corresponding OTV propellant needed.

The Shuttle flight history for each option is shown, with LG1 totalling 187 and LG2 408. This large difference at $19.1 billion per flight represents a $4.2 billion cost difference as shown in the lower portion of the chart. The large number of Shuttle flights would warrant the use of a growth Shuttle which could save $1.1 billion, subtracted from the $4.2 billion. The $1.1 billion was derived from a savings of 309 Shuttle flights at $19.1 million each ($5.9 billion), mitigated by the cost of 152 growth-Shuttle flights at

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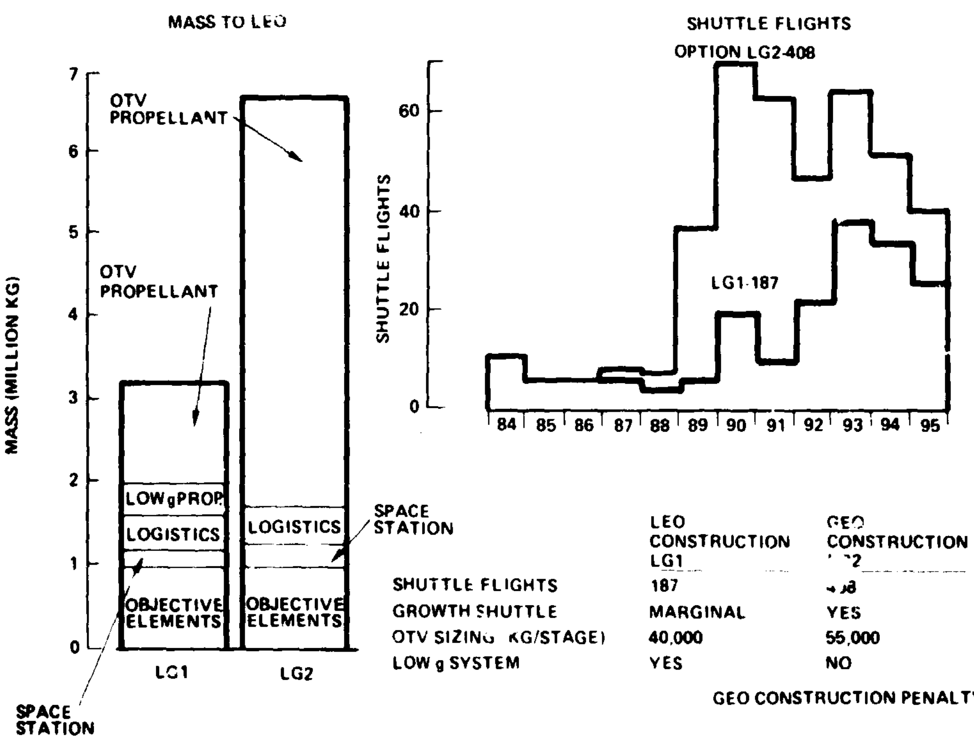

	LEO CONSTRUCTION LG1	GEO CONSTRUCTION LG2	Δ COST
SHUTTLE FLIGHTS	187	408	$4.2 B
GROWTH SHUTTLE	MARGINAL	YES	$-1.1 B
OTV SIZING (KG/STAGE)	40,000	55,000	N.C.
LOW g SYSTEM	YES	NO	$-0.5 B

GEO CONSTRUCTION PENALTY - $2.6 B

Figure 6-5. LG Transport Requirements To Low Earth Orbit

$25 million each ($3.8 billion), plus a $1.0 billion growth-Shuttle development cost. These factors are treated parametrically in Section 7.

Additionally, Option LG2 does require a larger OTV to satisfy crew rotation requirements; however, no cost difference was factored in. A low-g transfer system for LG1 would be required. The development cost estimate is $0.5 billion. The net cost difference due to LEO transportation is thus $2.6 billion between LG1 and LG2.

6.3 TRANSFER TO GEO

SPS (TA-3) was analyzed to examine the transfer influences. The LEO-to-GEO orbit transfer is dependent upon the type of system used, and the thrust level. As seen in Figure 6-6, the transfer time varies from 5.25 hours at 0.1g to 70 days at 10^{-4}g for continuous-thrust capability.

The GEO objective elements for LG2 are constructed in GEO and the material transferred stowed on a normal OTV mission. In LG1, the GEO objective elements are constructed in LEO and transferred to GEO intact

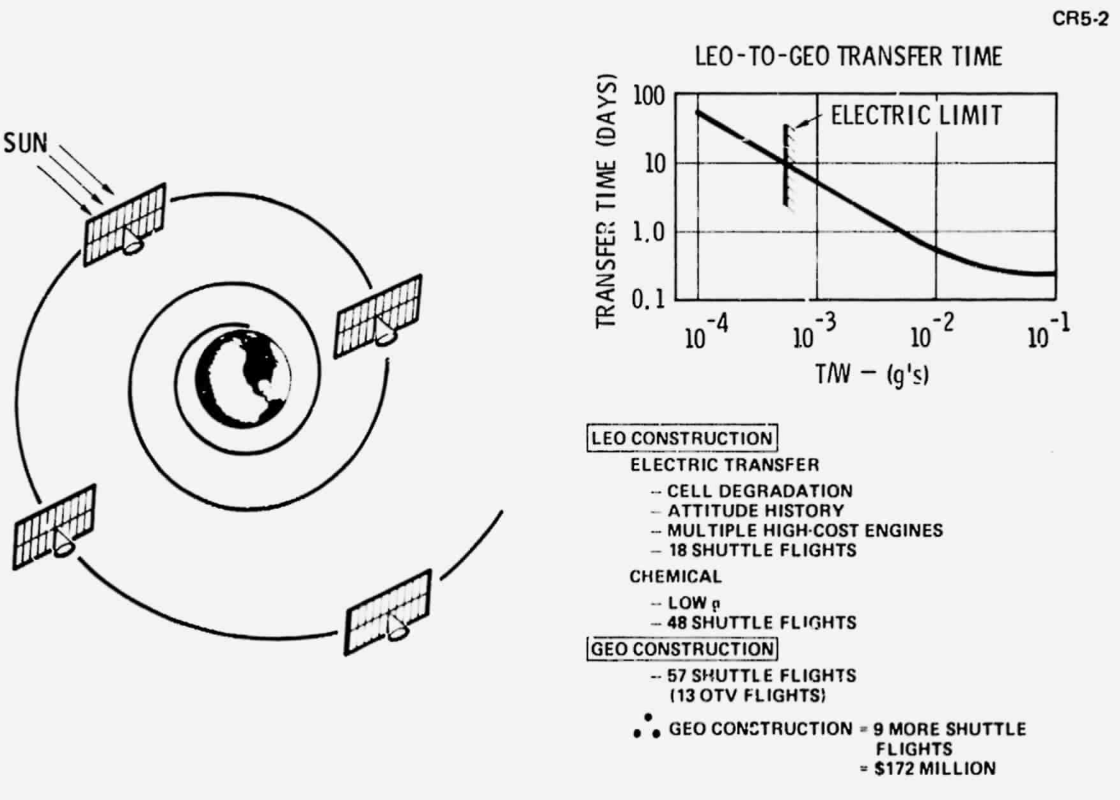

Figure 6-6. SPS (TA-3) Transfer To GEO

using a low-thrust system. For TA-3, the 21 MW array can be used to provide power for an ion-engine thrust system. The g-level limit is about $5(10)^{-4}$g based on a power-limited system. The transfer trajectory would consist of a spiral trajectory as shown. For a continuous-thrust system, the transfer time would be about 10 days. Since the array is not always in the sun and the thruster not always aligned, the time would increase. The resulting exposure of the solar cells in the lower Van Allen belt can cause significant degradation – up to 40%.

As seen on the trajectory, a body-mounted engine system would be properly aligned on only a small portion of the mission. Large gimbaling angles are needed and multiple engine systems are probably required. The yaw or out-of-plane angle variations become large and vary at orbital frequency to provide velocity where it is needed as the orbit inclination is depressed.

A low-thrust transfer using chemical systems (perhaps reusable or even expendable OTV's) could also be used. The orientation problem would be overcome and the transfer could be faster to reduce the solar cell degradation. The extra Shuttle flights needed are more than compensated for by not having to buy an electric propulsion system at about $0. 5 billion. Thus, from a transfer standpoint, the differences in LG2 and LG1 are 9 Shuttle flights more for the GEO construction case if the recommended low-g chemical system is assumed for LG1.

6.4 ORBIT KEEPING

The four objective elements being considered for LEO or GEO construction were analyzed to determine the relative orbit-keeping differences. At geosynchronous, orbit-keeping is needed to combat sun/moon effects, triaxially of earth, etc., at a total yearly cost of about 45 m/sec. Since these four will operate at GEO, they must be designed for this capability. If they are constructed at LEO, the aerodynamic drag could cause large expenditures, depending upon the altitude, orientation, and density (function of solar activity cycle). As seen in Table 6-3, except for TA-3, the LEO/GEO differences are small. TA-3 would have a relatively large drag propellant requirement if operated with the array facing the sun (for test purposes). This could be alleviated by raising the altitude (the density is reduced by a factor of 2 for every 37 km altitude increase) or restricting the test time. In summary, the LEO/GEO orbit-keeping differences are not a major influence on the selection of LEO or GEO as the construction site.

6.5 ORBITAL FORCES AND MOMENTS

SPS (TA-3) was examined to calculate the forces that would be applied at LEO and GEO. As seen in Table 6-4, gravity gradient and aerodynamic torque differences are large from LEO to GEO. This would require an attitude control system for the LGl option during the LEO tests. It would not be needed at geosynchronous orbit. The penalty may not be great, since the system used for orbit-keeping would probably suffice, and/or uncontrolled excursions of a few degrees would probably be acceptable for a short-duration test.

Table 6-3

LEO VS GEO ORBIT KEEPING

Monthly Propellant Required (kg)					
Orbit	Objective Element	Mark II Radiotelescope (2×10^4 Kg)	27-Meter Multibeam Lens (2.9×10^4kg)	SPS TA-3 (3.1×10^5kg)	Cross-Phased Array Antenna (63,500kg)
LEO (400m)	1984-1991	70	80	1,400* 5,000**	130
	1987-1991	150	160	3,200* 14,000**	250
GEO		30	40	420	90

*Array parallel to velocity vector

**Array perpendicular to sun vector

Table 6-4

ORBITAL FORCES AND MOMENTS
SPS TA-3

	LEO (400Km)	GEO	
Gravity Gradient (Max) (orientation dependent)	1,160 to 82,830 n-m	5 or 342 n-m	1n-m= .74ft-lb
Aerodynamics (Max)	3,480 to 69,640 n-m	Negligible	
Centrifugal force (Max)	40.3 n	0.17n	1n= .225 lb
Thermal cycling	High (must be relieved)	Same	
Docking, solar Pressure etc.	Small	Small	

6.6 PLASMA LEAKAGE

High-voltage equipment, particularly solar arrays, operating in space may be subject to substantial losses due to leakage caused by the space plasma. Figure 6-7 illustrates the nature of this potential problem for TA-2 and TA-3 (TA-1 has a low-voltage solar array).

The figure at the left shows the power loss as a function of altitude due to electron and ion collection for a 90% insulated, $139m^2$ solar array operating at 2,000 and 16,000V.* The potential for leakage exceeds the array output capability at 16,000V and altitudes below 1,000 km; the peak leakage occurs at 300 km. The leakage is a function of the plasma density, which is a function of altitude and the 11-year solar cycle. The curves are for the peak of the solar cycle (4×10^6 e/cm^2) and are conservative for TA-2, which

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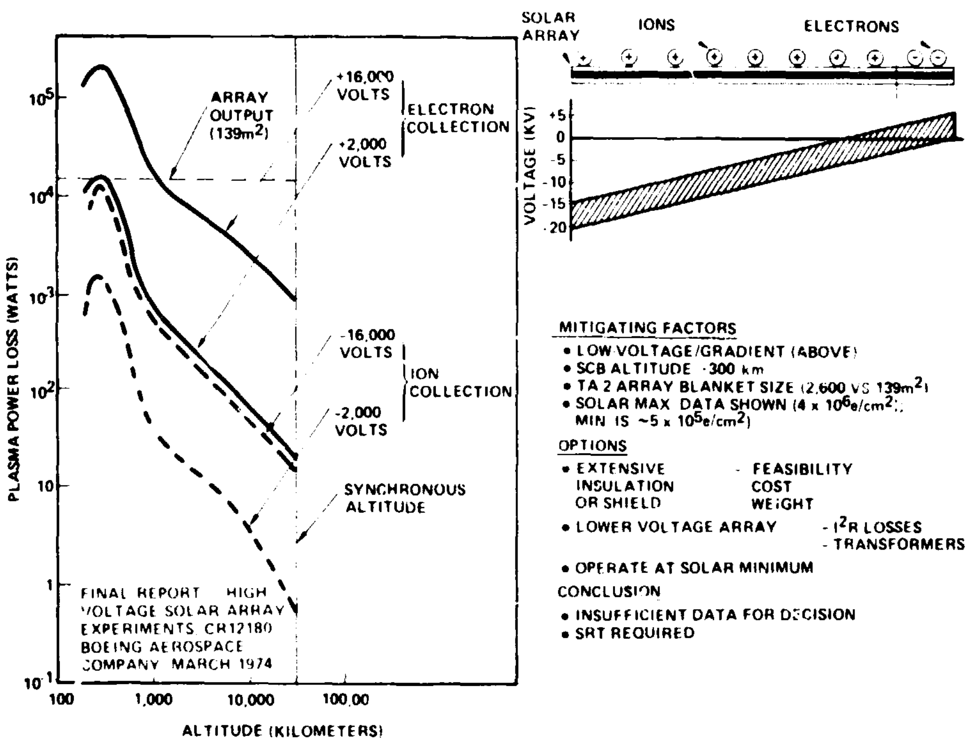

Figure 6-7. High-Voltage Solar Array Plasma Leakage

*Reference - Oman, H., Boeing, "Cost of Earth Power from Photovoltaic Power Satellite"

will fly near the solar minimum (5×10^5 e/cm^2). The curves were calculated using Langmuir equations with constant-charge spheres used as a model.

Electron collection is seen to be a more severe problem than ion collection, because of the greater electron mobility. A solar array generating a 20,000V differential is expected to assume the voltage levels depicted in the upper right, because of these differences in mobility. The resulting low voltages (with the voltage gradient depicted) will attract relatively few electrons and ions compared to the constant high-voltage case (e.g., a uniform 16,000V across the entire array) assumed in the left-hand figure. The leakage loss for the low-voltage case will be much less than that depicted on the left figure.

Other factors mitigating the severity of the TA-2 and TA-3 problem in LEO relate to: (1) SCB altitudes greater than 300 km, which puts the losses to the right of the peak values; (2) large solar arrays are less affected than smaller ones; (3) TA-2 will operate near solar minimum. It is believed that this will not be a severe problem for TA-2 and TA-3. Should this prove incorrect, options to resolve the problem include: (1) development of substrate and solar cover insulation free of pinholes (which rapidly enlarge and cause leakage), or electrically biased screens; (2) reduction of array voltages with a step-up transformer; and (3) shifting test operations to GEO.

Based on the mitigating factors stated and the worst-case modeling used for the calculations, it is felt that the leakage problem will be substantially reduced after thorough analysis and test. Thus, no penalty was imposed on the LEO/GEO construction issue.

6.7 RADIATION ENVIRONMENT INFLUENCES

The radiation environment at LEO and GEO is different and could have some effects on the LEO/GEO construction issue. The allowable doses (REM) for crewmen are as shown below:

Exposure Days	Skin	Eyes	Marrow
30	75	37	25
90	105	52	35
180	210	104	70

The skin dose shown in Figure 6-8 is usually the limiting dose and most difficult to shield. At LEO or GEO a ~ 1 gm/cm^2 Space Station wall would reduce the dose to well below the allowable. The Solar Cosmic Ray (SCR) dose at GEO is dependent on the size of flare received. The range of dose shown as a function of shield thickness is for expected 5 to 9 flares per year. A biowell is needed at GEO with a thickness of ~21 gm/cm. This would require a biowell of 8 cm thickness which, for a 6-man capacity, would have a mass of about 3,640 kg. No biowell is needed at LEO since shielding is provided by the magnetic field.

The requirements for EVA radiation shielding were determined by comparing the allowable dose to that received inside a 1 gm/cm^2 Space Station, then allowing the difference to be the allowable EVA exposure dose. The relationship between mission duration, EVA exposure, and required suit thickness is shown in Figure 6-9 for LEO (28.5° x 400 km) using skin dose as the limit. A 30-day mission with a total of 2 days of the 30 spend at EVA, would require a suit thickness of 0.31 gm/cm^2. The suit thickness drops off with mission duration for constant EVA exposure because the total allowable dose also increases. Planned EVA and mission duration points for the SCB mission are shown by the data points at 30, 90 and 180 days. A suit thickness requirement of from 0.31 to 0.49 gm/cm^2 is required. The potentially available suit thickness ranges from 0.1 gm/cm (STS suit) to 0.3 gm/cm^2 (1985 EVA suit). An increase appears needed to stay within the overall allowable dose criteria.

The GEO overlay shows the same data for the GEO orbit. The increased electron environment at small shield thicknesses would require a thicker suit at GEO. The previous requirement range would be extended to 0.5 to 0.67 gm/cm^2. This comparison is for trapped radiation only. The effects of SCR are shown on the next chart.

SCR dose must also be considered in geosynchronous orbit -- at 28.5° LEO, the earth's magnetic field would shield the SCR protons. The GEO SCR dose is factored in as a function of biowell thickness, and would further reduce the dose allowed during EVA, thus requiring still thicker suits than shown

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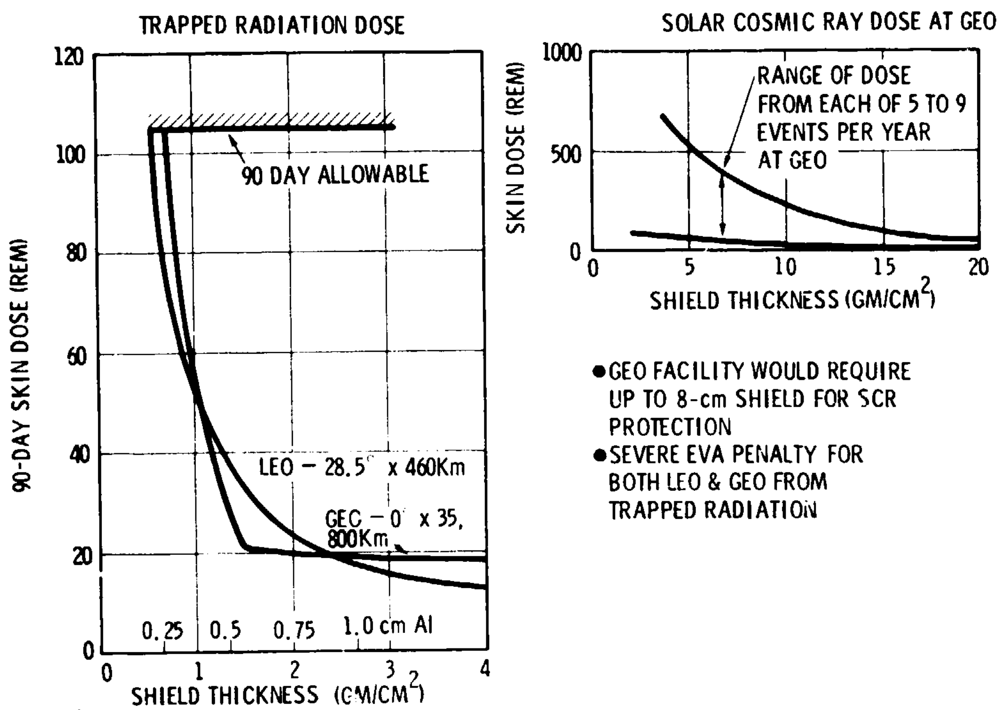

Figure 6-8. Radiation Environment Influences

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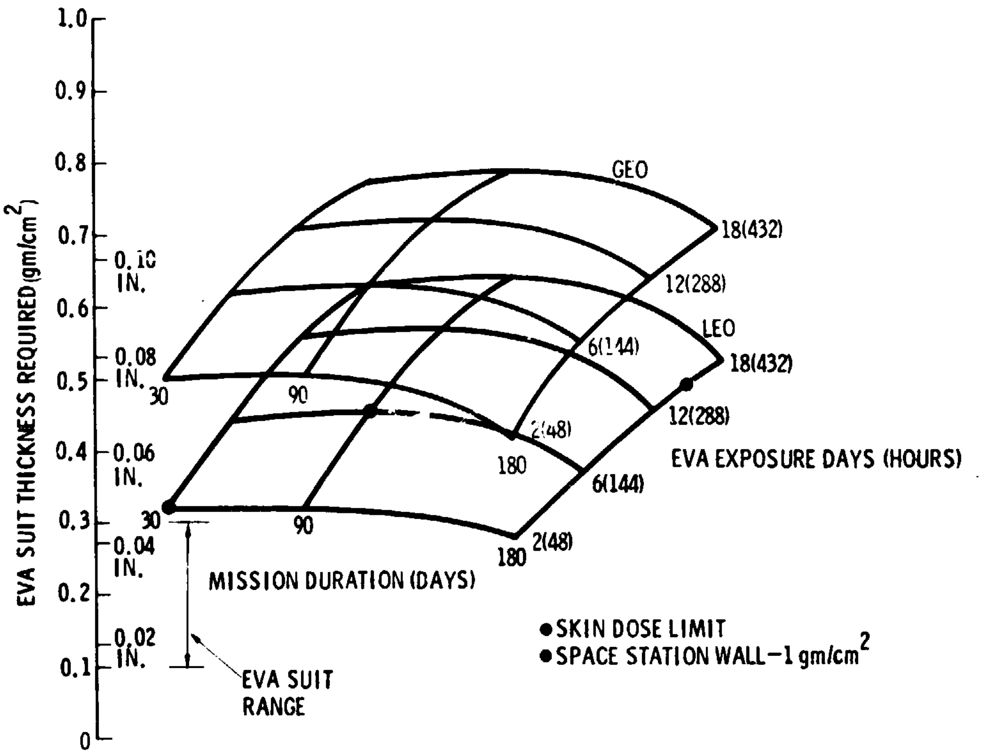

Figure 6-9. GEO and LEO Radiation Shielding

on the previous chart. This analysis was done for the 90-day mission duration curve from the previous chart which was used to calculate the data shown in Figure 6-10. A very thick biowell (38 gm/cm^2) would allow a relatively higher skin dose to be absorbed during EVA, thus the suit requirement is about the same as shown on the previous page. For a thinner biowell, the allowable EVA dose would decrease, thus requiring thicker EVA suits. The range is now increased by a few more gm/cm^2. The intense environment during a solar cosmic ray event would preclude EVA activity at GEO.

Clearly, there is a radiation penalty associated with extended duration and EVA exposure at GEO compared to LEO. In both cases, however, the EVA suit requirements exceed the planned suit thicknesses. It should be remembered that these calculations are for a thin shield in a region of the environment where dose is changing very rapidly with thickness, thus, the results are sensitive to theoretical and calculation error and changes in the environment. Thorough analysis of the radiation environment appears warranted prior to pursuing firm EVA suit requirements.

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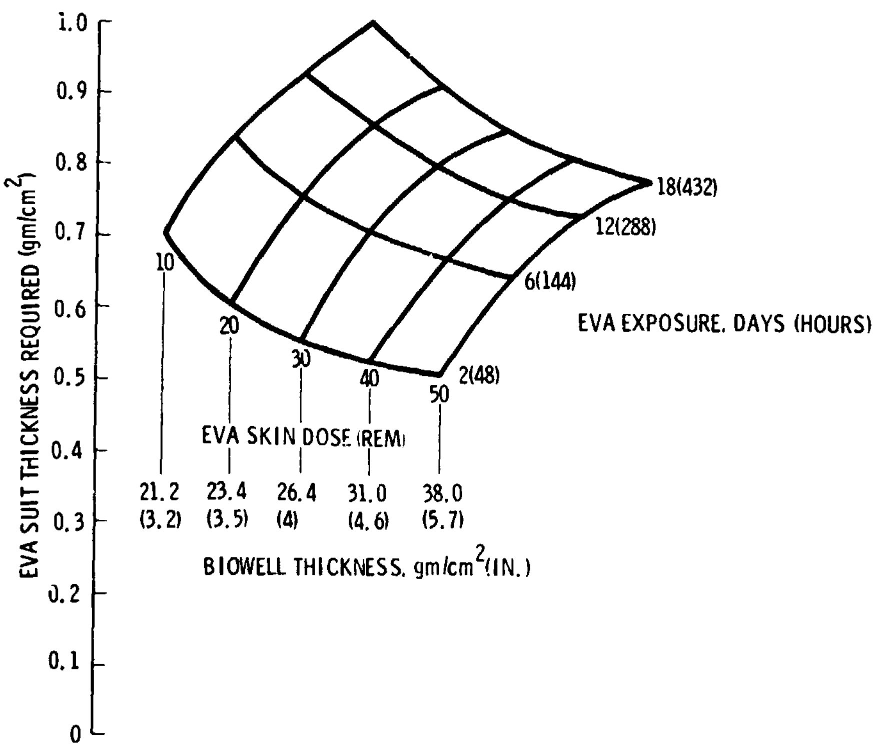

Figure 6-10. SCR Radiation Effect – GEO

6.8 LEO VERSUS GEO CONSTRUCTION SUMMARY

The evaluation of the major LEO versus GEO construction issues resulted in the summary comparison shown in Table 6-5. These conclusions are based on the objective elements analyzed -- primarily as influenced by SPS (TA-3).

LEO construction is preferred because it would save at least $2.6 billion over the GEO construction approach. Other advantages are that the current Shuttle is adequate to support the operations for the LEO construction case and the logistics are simpler.

The disadvantages of LEO construction are that a low-g transfer system is needed, but it is felt that an OTV concept can be used as the base for this system to reduce the cost and to move the solar cells quickly through the Van Allen belt to avoid radiation damage. The LEO attitude-control/orbit-keeping needed is a small addition. The plasma leakage problem may be serious, but at this juncture it is too early to tell. Adequate solutions through rigorous analysis and test are felt to be achievable should the problem persist.

The GEO construction technique does offer some advantages but the greater cost, the need to commit to a growth Shuttle, and the added radiation hazard, make it less desirable.

Table 6-5

LEO VS GEO CONSTRUCTION SUMMARY

	LEO Construction	GEO Construction
Advantages	Lower System Cost	Constructed in Situ
	Current Shuttle Adequate	Stowed Transfer to GEO
	Simpler Logistics	
Disadvantages	Low 'g' Transfer Needed (Use Chemical OTV)	Transportation cost $2.6 Billion More
	Additional Attitude/Orbit Control	Require More SCB Elements
	Solar Cell Degradation During Transfer	Requires Growth Shuttle
	Potential Plasma Leakage	Greater Radiation Hazard

Section 7
TRANSPORTATION SYSTEMS ANALYSIS

The Transportation Systems Analysis of Part 2 included transport from earth-to-LEO, transport from LEO-to-GEO, OTV concept definition, and systems analyses related to transportation. Assumptions used in the analyses included:

- Shuttle capability per 07700 - Volume 14.
- Growth Shuttle available if needed.
- Crew rotation - 180 days (LEO).
- Crew rotation - 90 days (GEO).
- OTV concept to be derived in study.

7.1 EARTH-TO-LEO TRANSPORTATION

The transport requirements from earth to LEO were determined by analysis of the objective element requirements, the SCB modules needed, logistics, crew rotation, and LEO-to-GEO transport support, i.e., OTV and propellant needed.

The objective element requirements are discussed in Section 3. Their mass to LEO requirements are summarized in Table 7-1. The integrated transport requirements for each program option are summed up in Figure 7-1.

Transportation requirements to LEO were calculated for each of the program options being evaluated in Part 2. The shaded areas indicate the mass required in direct support of the respective objective areas. The remaining portions of the transport requirements include the Space Station elements, logistics, and OTV propellant. The four LEO options require about 500,000 kg to LEO over the respective duration spans. The objective element fraction is about one-third of the total, which is considerable for these modest degree-of-accomplishment options. The Space Station elements represent about 20% of the total LEO option requirements.

Table 7-1

OBJECTIVE ELEMENT MASSES

Item (1)	Mass (kg)	Resupply (kg/yr)
TA-1	1,500	----
TA-2	5,000	1,000 (2 yr)
TA-2 Tooling	(3 STS flights)	----
TA-3	295,000	20,000 (3 yr)
TA-3 Tooling	49,380	20,000 (1-1/2 yr)
		3,000 (2 yr)
SP - Bioprocessing	10,000	1,500 (1 yr)
- Ultrapure Glasses	10,000	500 (1 yr)
- Process Optimization	30,000	3,000 (1 yr)
- Silicon Ribbon Shaped Crystals	50,000	7,500 Total
- Commercial Production	300,000	130,000
Radiometer - 30m	4,500	----
- 100m	13,600	----
- 300m	90,700	9,100 (2 yr)
Multibeam Lens Antenna	28,000	2,800 (1 yr)
Cross-Phased Array	64,000	6,400 (2 yr)
MDL	14,000	6,000
LWIS	750	100
Mk II Telescope	10,000	
Sensor Development and Test	10,000	2,000
Fabrication and Assembly	14,000	2,000

(1) Description of objective element including Part 1 Final Report.

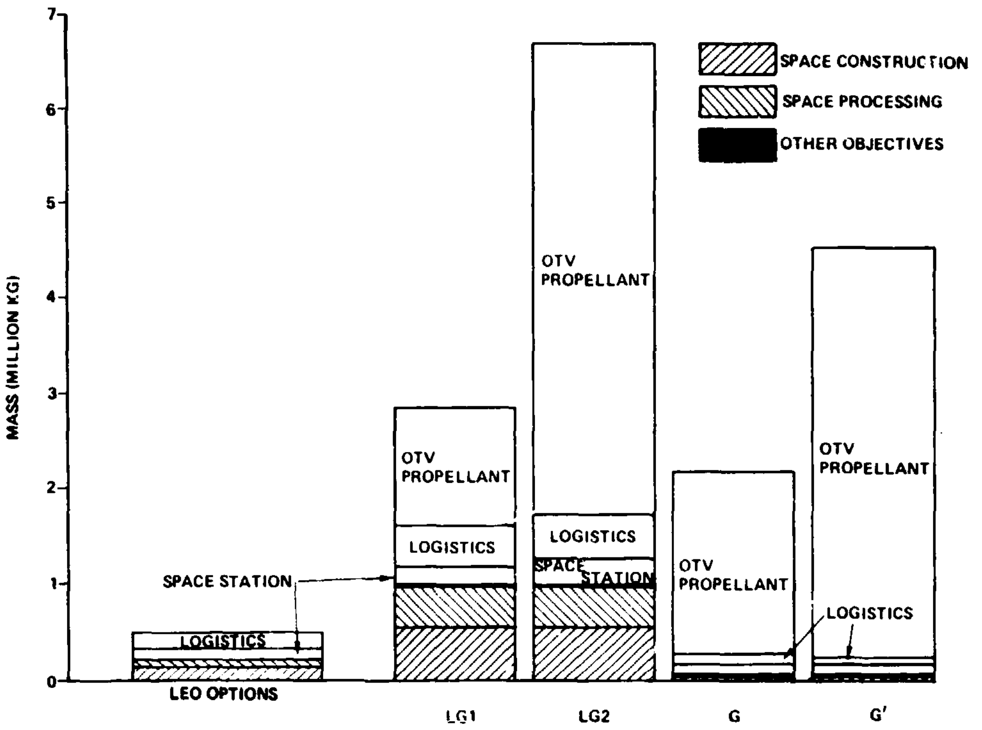

Figure 7-1. Transport Requirements to LEO

Program Options LG1 and LG2 require nearly three and seven million kilograms to LEO respectively. These options each accomplish the same objectives, and thus, have the same LEO objective transport requirements. Space construction for LG1 is done at LEO and the assembled systems moved to GEO as needed. The largest system, SPS TA-3, is transported using a high I_{sp} electric system. LG2 has increased requirements because construction is done at GEO and the objective components are transported by OTV. In addition, a larger (than LG1) crew complement and construction base is needed at GEO.

Options G and G' are limited-capability GEO options. The ratio of objective elements launched to date is low, 2% and 1%, respectively. G' has very large OTV propellant requirements because of the manned sortie mode to GEO.

The Shuttle was used as the carrier for the LEO transport. The Shuttle flights needed were derived for each option by analyzing the respective time-scheduled objective elements, SCB modules, logistics, OTV propellant, and crew rotation. Logistics consisted of the objectives resupply requirements of Table 7-1 and the crew requirements of ~4.5 kg/man-day (10 lb/man-day). The resulting Shuttle flights needed for the primary LEO options of Part 2 are shown in Figure 7-2. The total range from 44 to 62 total with one per month being the maximum rate – well within planned Shuttle capability. The front-end loading on these plots is needed to lift the equipment needed. Thereafter, resupply and crew rotation flights at two per year suffice. The Shuttle flights needed to support the LG1, LG2, G, and G' options are shown in Figure 7-3. As seen, a large contributer is the OTV propellant needed for LEO-to-GEO transfer.

The Shuttle flights needed to support the four GEO options vary from a low of 113 for Option G to a high of 408 for Option LG2. Maximum flights per year for 39 for LG1, 70 for LG2, 38 for G, and 55 for G'. Clearly, these high rates would tax the Shuttle capabilities. In addition, a major portion of the flights are for OTV propellant delivery, which could be transported in larger increments. Thus, a LEO delivery system of larger capability might be warranted to reduce the number of flights, more efficiently transport propellant, and reduce costs.

The economics of using the growth Shuttle were determined by calculating the potential cost savings over an all-Shuttle mode, then relegating that sum for potential development of the growth Shuttle. This is shown in Figure 7-4 as a function of growth Shuttle capability and cost per flight. For example, considering LG1, the reduced number of flights allowed by the use of a growth Shuttle resulted in the cost savings shown in the upper left. All or part of this potential savings can be applied to the development cost of the growth Shuttle to determine the merits of the system. If a 50,000-kg capability growth Shuttle, which cost $25M per flight, were available, the net savings over the all-Shuttle mode (at $19.1M per flight) would be about $750M. If the growth Shuttle could be developed for less than that amount, a net savings would be made. The decision criteria (amount necessary to be saved to select the growth Shuttle) would be dependent on return on

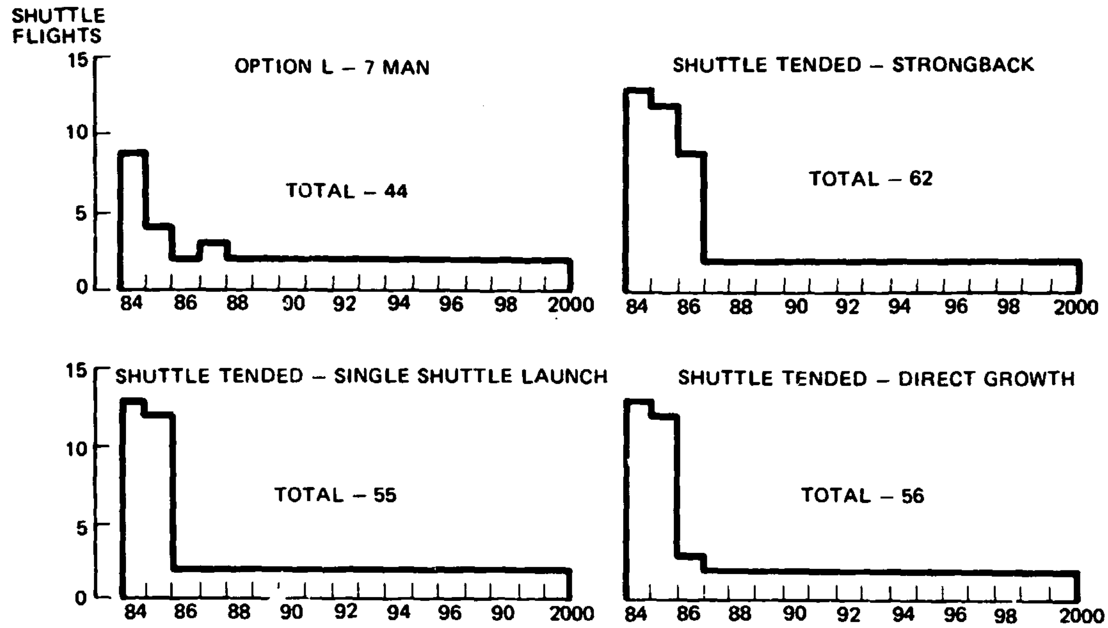

Figure 7-2. LEO Option Shuttle Flights

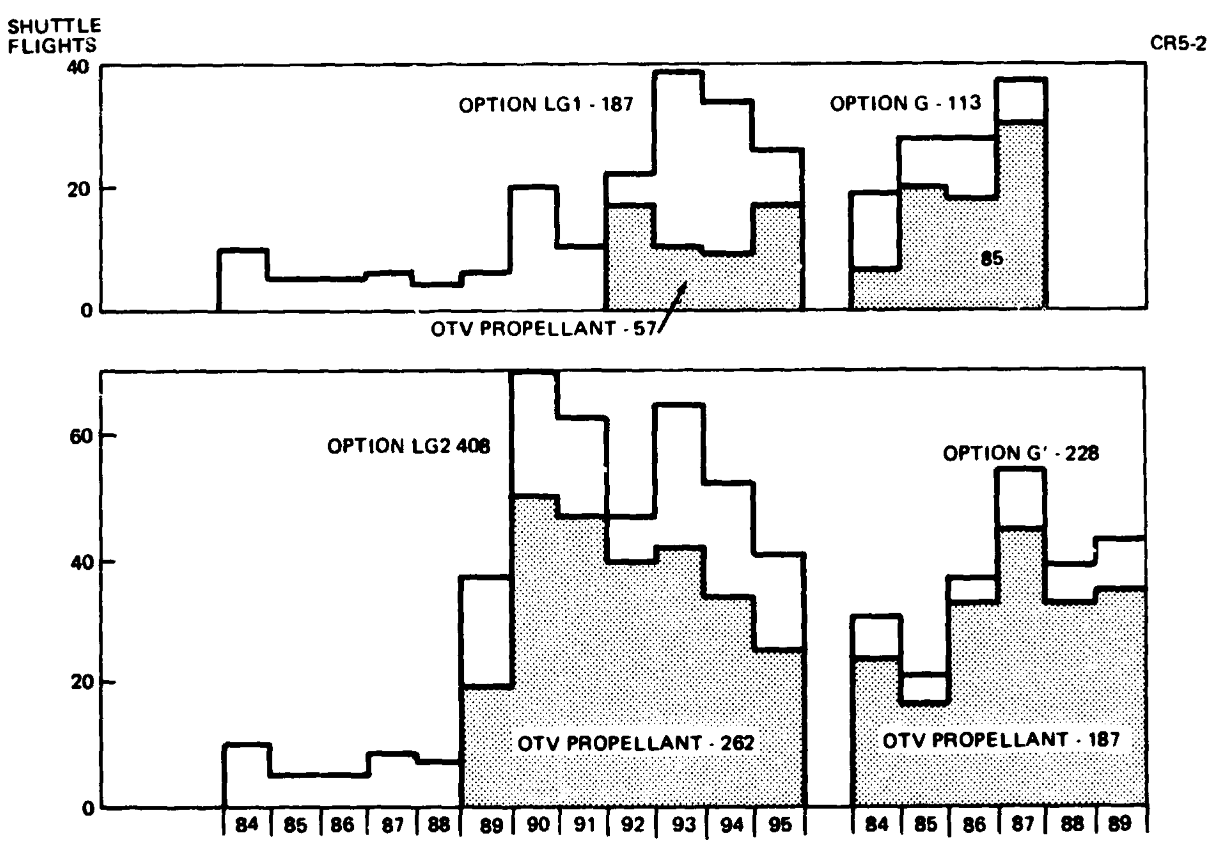

Figure 7-3. GEO Program Option Shuttle Flights

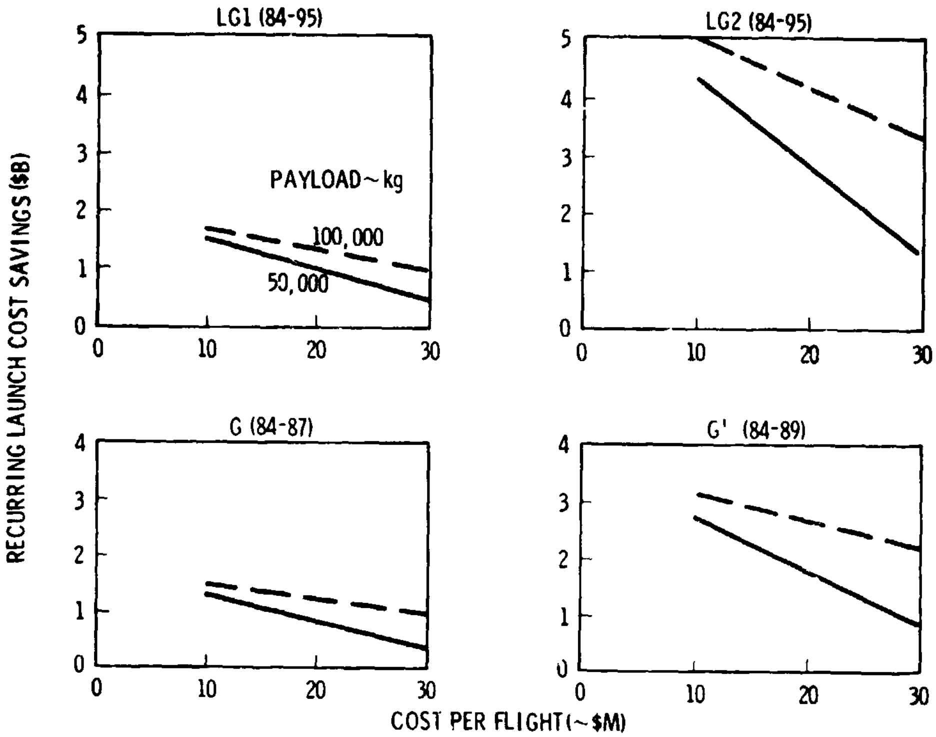

Figure 7-4. Growth-Shuttle Investment Regimes

investment, risk, and other factors. The LG2 case appears to be a good candidate for a growth Shuttle. The previously mentioned example ($25M per flight and 50,000-kg capability) would allow a potential of $2.2B available for savings and growth Shuttle development. If a larger (100,000 kg) growth Shuttle were used or the per-flight cost reduced, the development/savings made available would be even greater.

Option G data are similar to those of LG1, while Option G' appears to present a case for the growth Shuttle. However, both G and G' would require the growth Shuttle early (1984 to 1987 and 1984 to 1989 time frames). This would impose a burden on the early funding limits, hence would probably not be a desirable choice.

7.2 LEO-TO-GEO TRANSPORTATION

The LEO-to-GEO transport requirements were analyzed and system concepts to accommodate them formulated. This included OTV, crew module, and

electric propulsion systems. OTV requirements were calculated for each GEO program option. LG1 requirements are shown in Figure 7-5 by year for both the delivery and round-trip missions. The payload for the delivery mission consists of the items identified, while the round-trip payload is the crew module and some objective element material. As seen, there are large items to be delivered — the cross-phased array and the multibeam lens. Requirements for the other GEO options are included later.

The numerical distribution of delivery and round-trip payloads for Option LG1 is shown in Figure 7-6. As seen, most of the payloads are under 20,000 kg for the delivery mission and 7,000 kg or under for the round-trip mission. These requirements were tabulated for each GEO program option. The delivery or round-trip value at which the OTV should be designed was then determined. These data suggest that the OTV design capability should be 20,000 kg for delivery and 7,000 kg for round-trip.

The crew module requirements were specified and the resulting design weight characteristics determined as shown in Figure 7-7. Thus, the 7,000 kg allowance is more than adequate for a 4-man module.

Potential OTV designs were evaluated in terms of their compatibility for launch to LEO using Shuttle. As seen in Figure 7-8, a complete stage launched in the Shuttle bay would be limited in length to a capacity of 68,000 kg of propellant. The OTV concepts were space-based, i.e., launched empty and fueled on orbit. If the stage was divided into an LH_2 tank and a LO_2 tank and engine package, the capacity would be extended to 119,000 kg. These data were than used in both single and two-stage OTV performance calculations to be applied to the requirements discussed earlier. All elements are assumed reusable.

These parametric OTV capabilities were then compared to the mission requirements to determine the sizes needed. Delivery and round-trip payload capabilities are shown in Figure 7-9 overlaid on the mission requirements for Option LG1. Performance capabilities include single and two-stage OTV's

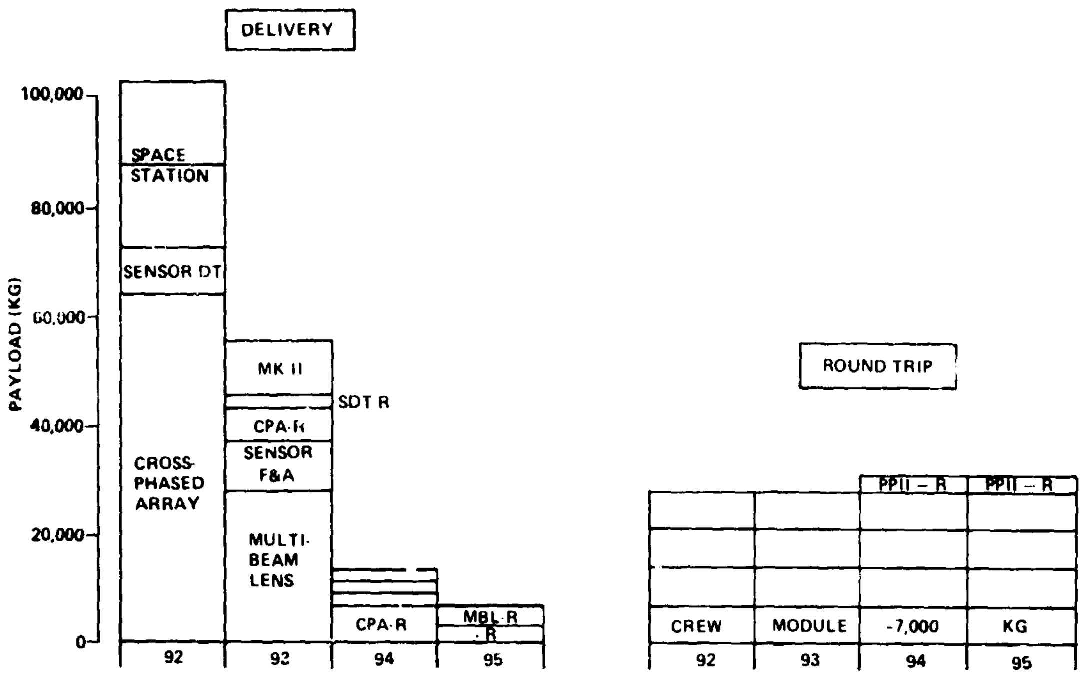

Figure 7-5. OTV Requirements - LG1 Payload Distribution

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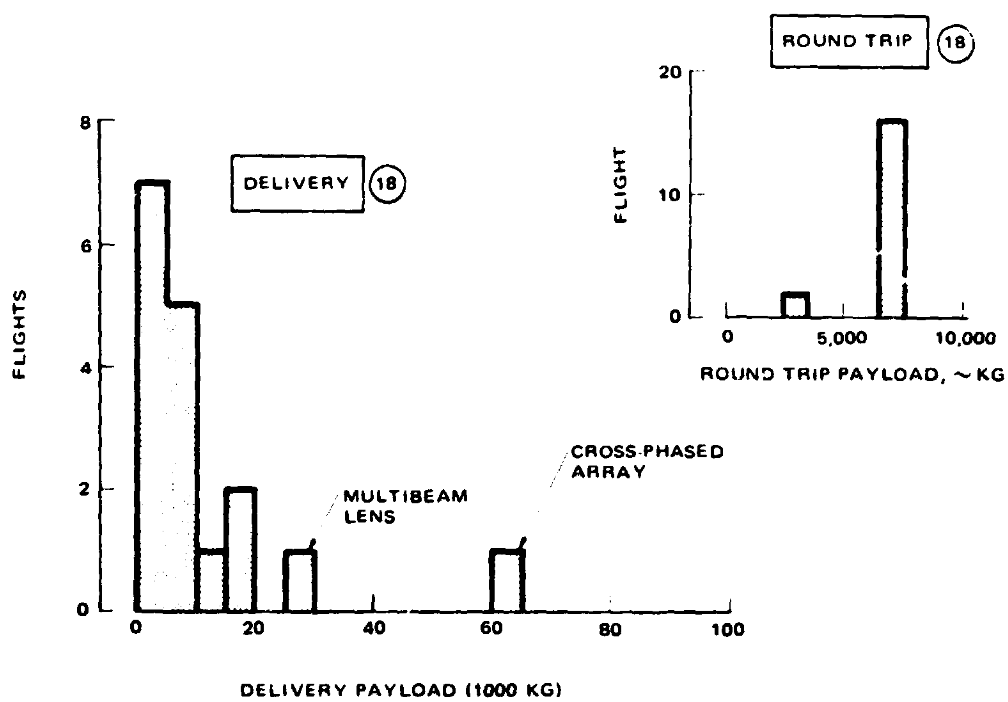

Figure 7-6. OTV Requirements - LG1

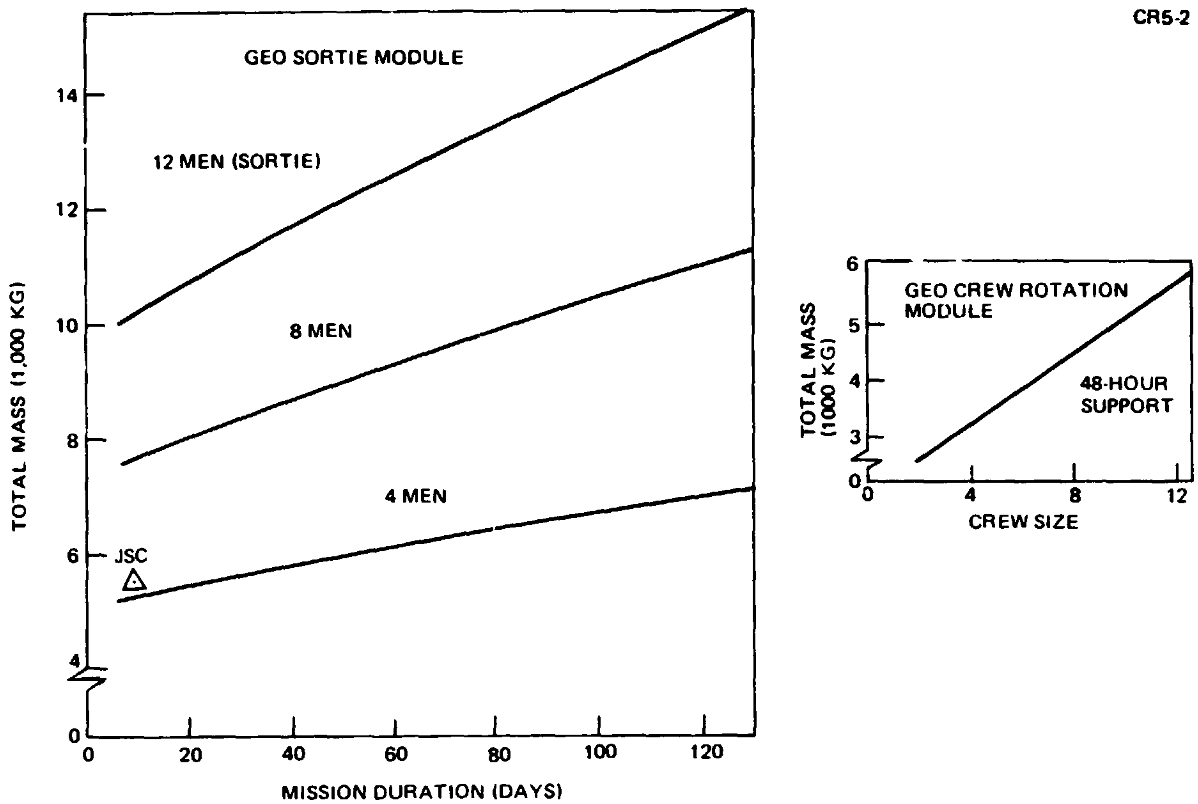

Figure 7-7. GEO Crew Module

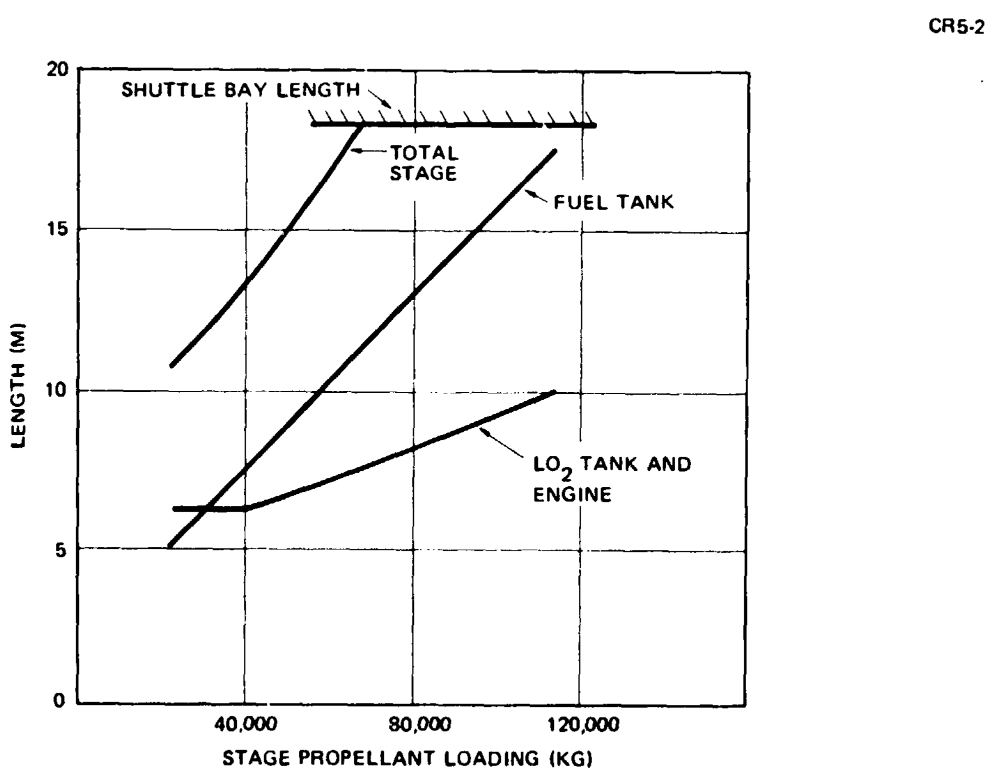

Figure 7-8. OTV Capacities

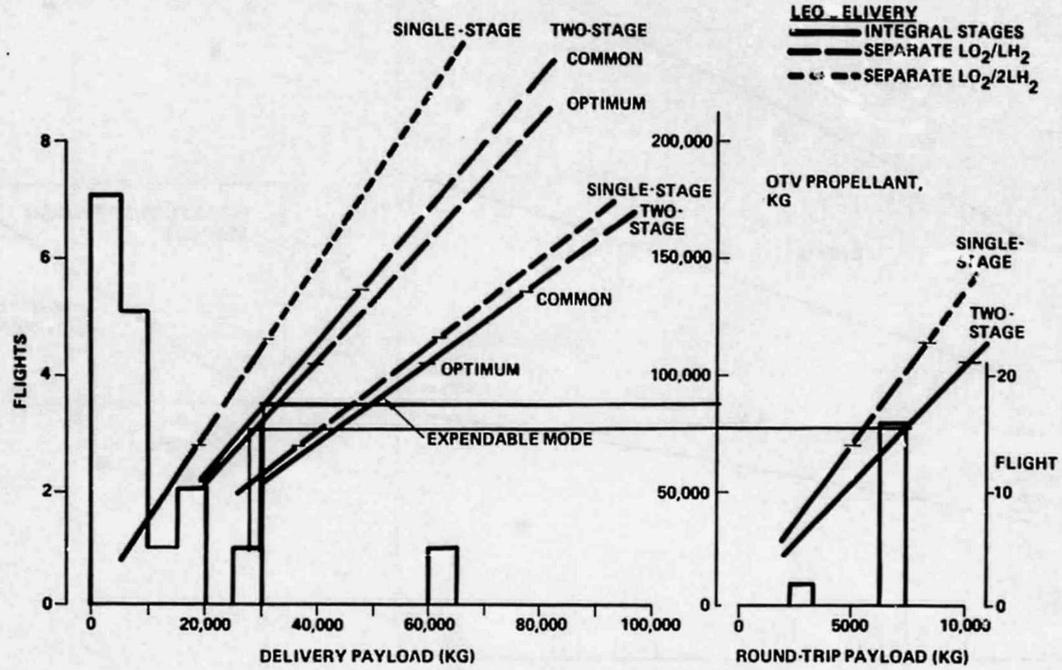

Figure 7-9. OTV Requirements/Capabilities — Option LG1

with the latter considered in both optimum and common stage configurations. The optimum consists of sizing the two stages for maximum performance, which is a propellant loading split between Stages 1 and 2 of about 2/1 for delivery missions and 55/45 for round-trip missions. For the common stage design, both stages are the same size. All the stages are reused in the primary mission mode; however, the capabilities for delivery in an expendable mode were also calculated to extend the capability for outsized payloads. The tic marks on each performance line indicate the transition points from integral stages to separate LO_2/LH_2 tank designs. The center ordinate of the chart is the total OTV propellant loading common to both the delivery and round-trip performance lines.

The bulk of the delivery missions (15 of 17) require less than 20,000-kg capability. This could be accomplished by both single- and two-stage OTV's, the single stage requiring 65,000 kg of propellant and the two-stage requiring about 50,000 kg. When the ground-trip requirements (7,000 kg) are

considered, a propellant loading of 100,000 and 80,000 kg would be required for the single- and two-stage OTV's, respectively. Note that the single-stage version would have to be launched in two pieces (LH_2 tank and LO_2 tank/engine) and assembled in orbit. Also note that the 80,000-kg two-stage OTV could accommodate the 28,000-kg delivery mission. Clearly, the 64,000-kg payload would size an OTV beyond that which would be used efficiently for 34 of the 35 LG1 flights. This mission would be accomplished by special means, probably multiple OTV elements used in an expendable mode. The propellant savings and flexibility of the two-stage OTV over that of the single stage resulted in the two-stage selection for Option LG1. The reduced OTV propellant alone would result in a $320M saving due to decreased Shuttle flights (17 x $18.9M). The common stage design was chosen over the optimum concept for commonality reasons, the performance difference being small. Thus, an 80,000-kg propellant common two-stage OTV (two 40,000-kg stages) was selected for LG1.

This analysis and selection process for sizing an OTV was done for all four program options per the previous example. The sizing data for all program options is discussed in Volume 3, Book 2. The types selected, sizes, and major influence for each option are shown in Table 7-2.

Table 7-2
INITIAL OTV SELECTIONS

Option	Type	Propellant/ Stage (kg)	Payload (kg) Delivered	Round-Trip	Expendable	Major Influence
LG1	2-C	40,000	28,000	7,500	46,000	Delivery Payload
LG2	2-C	55,000	39,000	11,000	64,000	Expendable Payload
G	2-C	53,000	37,000	10,000	60,000	Round-Trip Payload
G	2-C	55,000	39,000 15,000	11,000	60,000	Round-Trip Payload and Delivery (1 Stage)

The two-stage common design OTV was selected for all four options based on the reduced logistics costs for propellant delivery and the commonality of design. The respective logistics cost savings of the two-stage OTV over the single stage due to reduced Shuttle flights at \$19.1M were LG1-\$340M, LG2-\$1.6B, G-\$560M, and G'-\$880M. The individual sizes for each option were selected by considering the delivery and retrieval requirements for each. The 40,000-kg propellant per stage for LG1 was discussed previously.

The OTV size selected for LG2 was 55,000 kg of propellant per stage. The basic requirement of 53,000 kg to meet the 10,000-kg round-trip requirement was raised to 55,000 kg to accommodate the delivery of the 64,000-kg cross-phased array. The OTV would be expended for this mission.

Option G analysis resulted in a 53,000-kg propellant per stage OTV to meet the 10,000-kg round-trip requirement. For Option G', a 55,000-kg OTV stage was selected. With this size, a two-stage OTV would be used to satisfy the round-trip mission requirement of 11,000 kg and one of the two common stages would be used for the 15,000-kg delivery mission.

Figure 7-10 shows that the basic two-stage OTV needed to place 28,000 kg of payload at GEO requires 33,000 kg propellant per stage at an Isp of 462 sec, a payload of 0.91, and zero values for the other parameters shown. The stage growth sensitivity as a function of these design factors was calculated as shown. As seen, each parameter has a significant effect on the stage size needed — especially λ', dry weight contingency, and payload growth. The cumulative effect of these typical values would increase the stage size needed to deliver 28,000 kg of payload from 33,000 kg to 50,000 kg propellant required. Careful assessment of these values must be established to adjust the initial sizing values selected. The Isp, λ', and dry weight contingency are OTV system parameters while the flight propellant reserve, maneuver velocity, and payload margin are mission-determined. Past and current stage systems were reviewed to determine achievable stage parameters.

The OTV concept selected for development in the study was a two-stage common space-based reusable OTV with each stage sized to the maximum that could be launched on a single Shuttle flight.

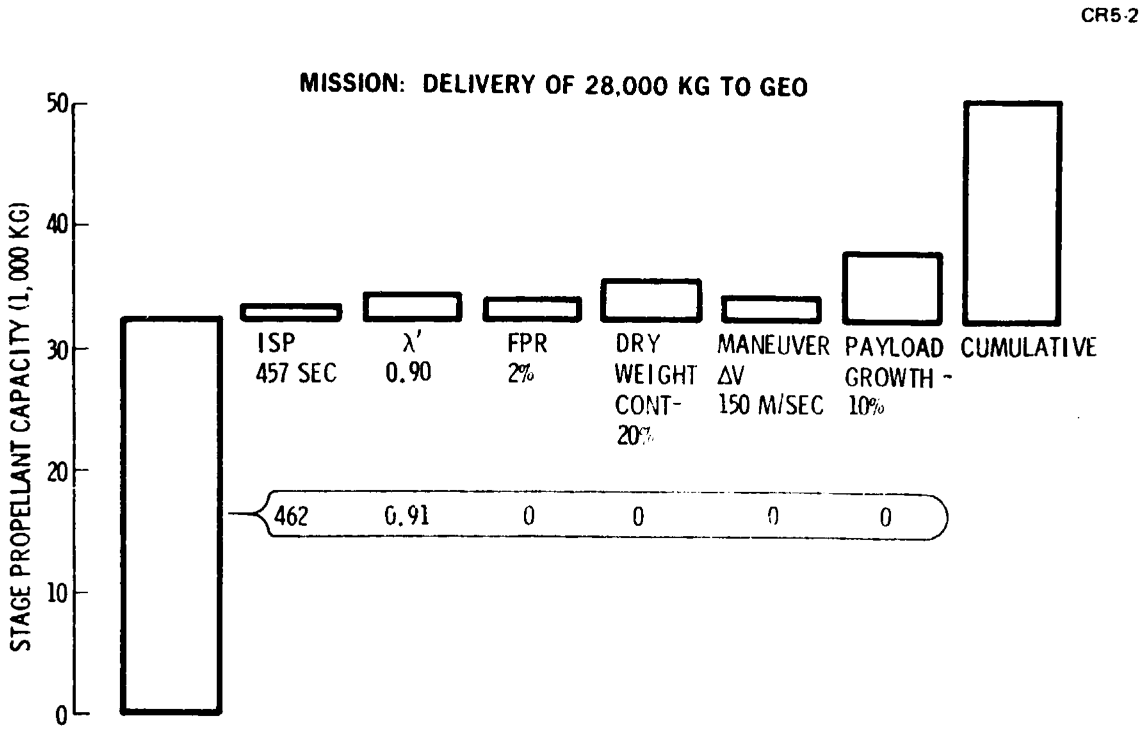

Figure 7-10. OTV Size Sensitivity

The basic mission profile for the OTV is shown in Figure 7-11. The reusable OTV will be space-based in LEO, and will be used either to deliver payloads to GEO or to carry payloads on a round-trip from LEO to GEO. Propellants will be delivered to the OTV via a Shuttle tanker; the OTV will be carried to LEO empty.

The first-stage OTV provides the initial boost to the second-stage OTV and payload for the orbit transfer. After shutdown and separation, it then coasts back to LEO, orbits, and awaits return of the second stage. Meanwhile, the second stage completes the transfer, and circularizes at GEO. After mission objectives are met, the second stage OTV deorbits and transfers back to LEO, where it circularizes and rendezvous with the first stage.

Major features of the baseline OTV are shown in Figure 7-12. The second-stage OTV with a single RL-10 category IIA engine is pictured. The first-stage would have two engines. The separation plane/docking mechanism is located just aft of the liquid oxygen tank thrust structure support points; the interstage will remain with the first stage. The docking mechanism will

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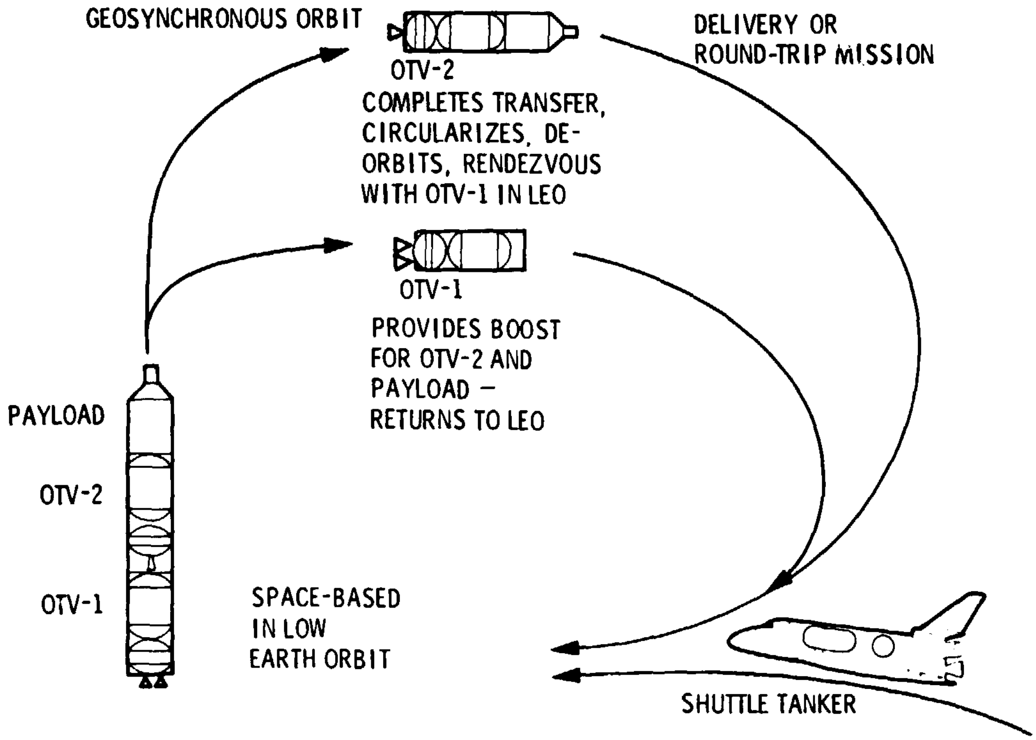

Figure 7-11. OTV Mission Profile

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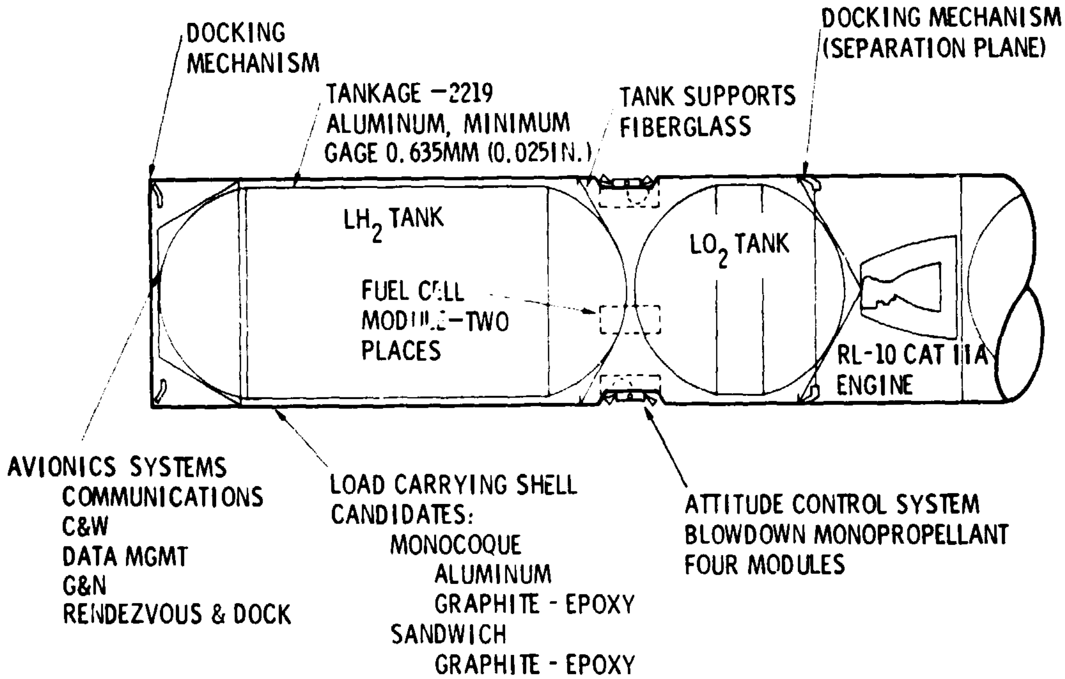

Figure 7-12. Baseline OTV Design

also be located at the front end of the forward skirt. If docking at other than the OTV diameter is require, an adapter will be used. The forward skirt/ forward dome area will also be the location of the various avionics subsystems: communications, caution and warning, data management, guidance and navigation, and rendezvous and docking.

The basic design concept includes a load-carrying outer shell with non-load-carrying tankage suspended inside by a fiberglass support structure. The tankage will be minimum-gage, 2219 aluminum, and will entirely covered with multilayer insulation (MLI. The outer shell, which provides meteoroid protection for the tankage, will be a lightweight structural design of composite monocoque.

The attitude control system as shown consists of four replaceable modules in the intertank area. A monopropellant (hydrazine) blowdown system appears to be most advantageous for OTV application. The intertank area would also be the location of the fuel cell modules used to provide the required stage power. Details of the OTV design are developed in Volume 3, Book 2 of this report.

7.3 SYSTEMS ANALYSIS

Two transportation related issues were also analyzed in Part 2. These included: (1) the applicability of IUS for LEO-to-GEO transfer of SPS elements early in the program and (2) the determination of the orbit inclination for a commercial space processing system.

The IUS was examined for potential use in placing Space Station program option elements in GEO-synchronous orbit early in the program. The current IUS development phase (verification) is examining various combinations of large and small expendable solids to achieve a wide range of mission requirements. The Geosynchronous configuration on the far left of Figure 7-13, is being studied for both DOD and NASA missions. Various other combinations (nonsynchronous) are being studied also, including the six-stage extreme right configuration for a planetary MSO mission. Various IUS stage combinations were analyzed for increased Geosynchronous capability, beyond the 2,700 kg provided by the two-stage version shown. The velocity split/stage size combinations resulted in the five configurations

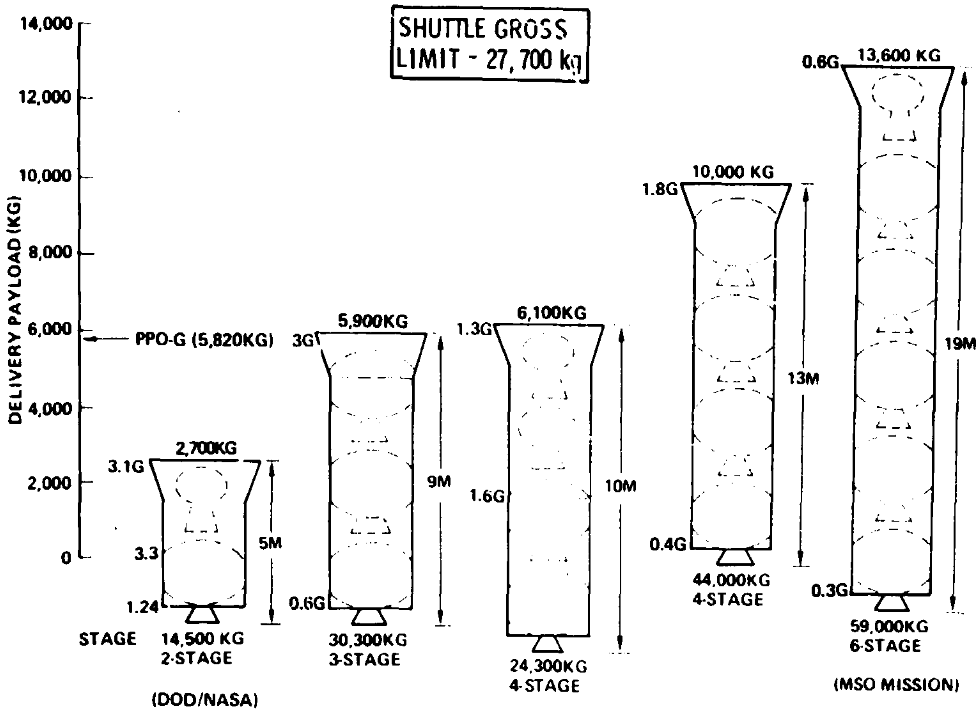

Figure 7-13. IUS Capability – LEO to GEO

shown for increasing capability to GEO. The middle configuration appears best for transferring TA-1 in that it provides the needed capability, can be launched as a unit in the Shuttle bay, and has a relatively low acceleration history. TA-1 was designed to withstand more than the 1.6 g applied during this transfer.

The space processing objective (commercial silicon ribbon plant) has high power requirements and high logistics requirements. The system was examined with respect to orbit inclination to determine if the cost savings of a reduced power system size at sun synchronous orbit could offset the increased cost of decreased Shuttle capability at that inclination.

The silicon ribbon processor examined requires 100 kW of power, an initial facility (sans power) of 60,000 kg, and a yearly logistics requirement of 100,000 kg as shown in Figure 7-14. The up logistics consists of raw materials needed to manufacture silicon ribbon. Down logistics would be required to return the finished product to earth for use there. For space use of silicon ribbon (primarily GEO) that produced at low inclination (28.5 deg) could be added on outbound Geo-synchronous mission while that

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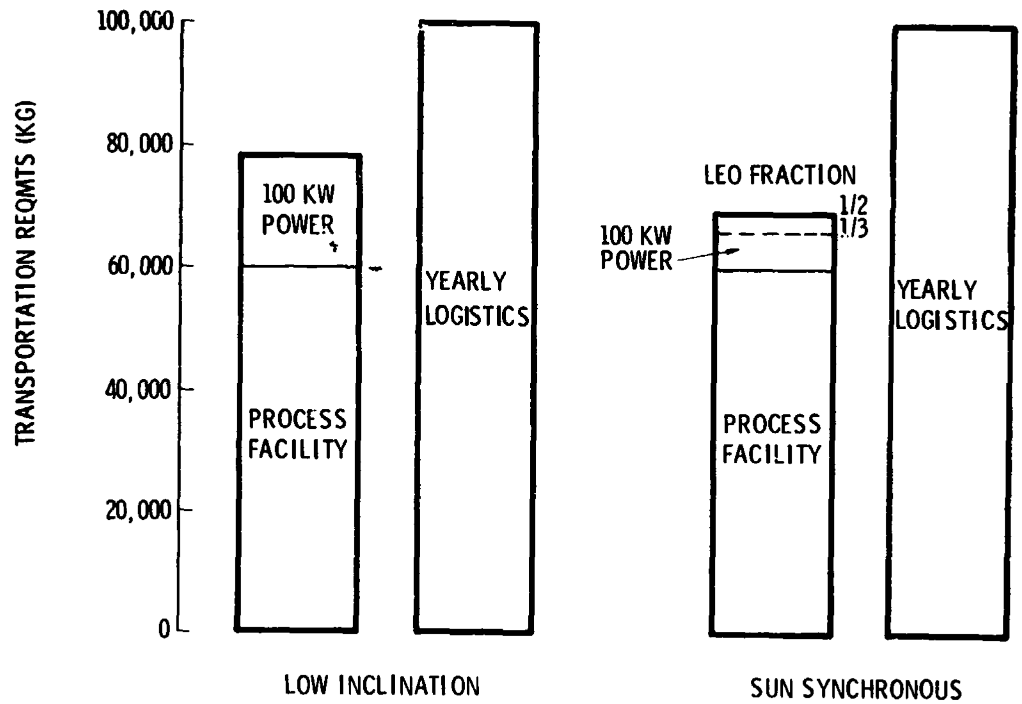

Figure 7-14. Commercial Processing Transportation Requirements

produced at sun synchronous would probably be returned to earth for retransport to 28.5 deg, then to GEO.

As seen, the basic mass requirements are large with the orbit inclination sensitive portion (power system) relatively small, about 10% or less of the total. Due to continuous sunlight at sun synchronous, the power system could be reduced in size by a factor of 2-3 from a 28.5-degree system. The storage batteries would be replaced with peaking batteries and the solar cells reduced by the ratio of sunlight available 1/.6 and also by not having to charge the storage batteries.

It should be noted that a sun-synchronous orbit consists of an orbit inclination and altitude combination such that the orbit regression is equal to the earth's orbit rate around the sun. The relationship is as follows:

$$\text{COSINE } i = -.098951 \left(1 + \frac{h}{Ro}\right)^{3.5}$$

The required orbit altitude/inclination relationship is tabulated below:

h - km	i - deg
300	96.7
400	97.0
500	97.4
600	97.8
700	[illegible]
800	98.

For continuous sunlight, the orbit altitude must be above 1,000 km altitude to be able to see over the Pole at winter/summer declination. Below 300 km, the orbit will dip behind the Poles in both winter and summer. For operation in the 300 - 1,000 km range, the orbit will pass behind the Pole for portions of each orbit in either winter or summer depending on initial conditions. The total time in sun would vary from 90 to 100% — depending on the altitude. It is assumed that the sun eclipse in these periods could be used for facility maintenance, etc., if the total operation could not be maintained.

The Shuttle flights needed to place the initial processing facility on orbit and maintain the 100,000 kg per year logistics are influenced by the inclination, operation altitude, and Shuttle landing limit. At 400 km altitude, the Shuttle can place 28,000 kg at 28.5 degrees inclination and 12,000 kg at sun synchronous. At 500 km, the capabilties are 25,000 kg and 10,000 kg, respectively. Thus, based on lifting capability, over twice as many flights would be required at sun synchronous as at 28.5 degrees inclination as shown by the comparison of the upper dashed line and the lower solid line in Figure 7-15. However, since a good share, if not all of the product is needed on earth, the number of flights at 28.5 degrees would be controlled by the 14,500 kg Shuttle landing limit indicated by the middle solid line. This compares more favorably with the flights needed at sun synchronous though the latter still requires about 25% more flights at 400 km and 60% more at 500 km. The operating altitude of a potential system would probably be nearer the 500 km figure. The Shuttle launch differences for each location can be compared to the power system cost differences to find the trade-off point.

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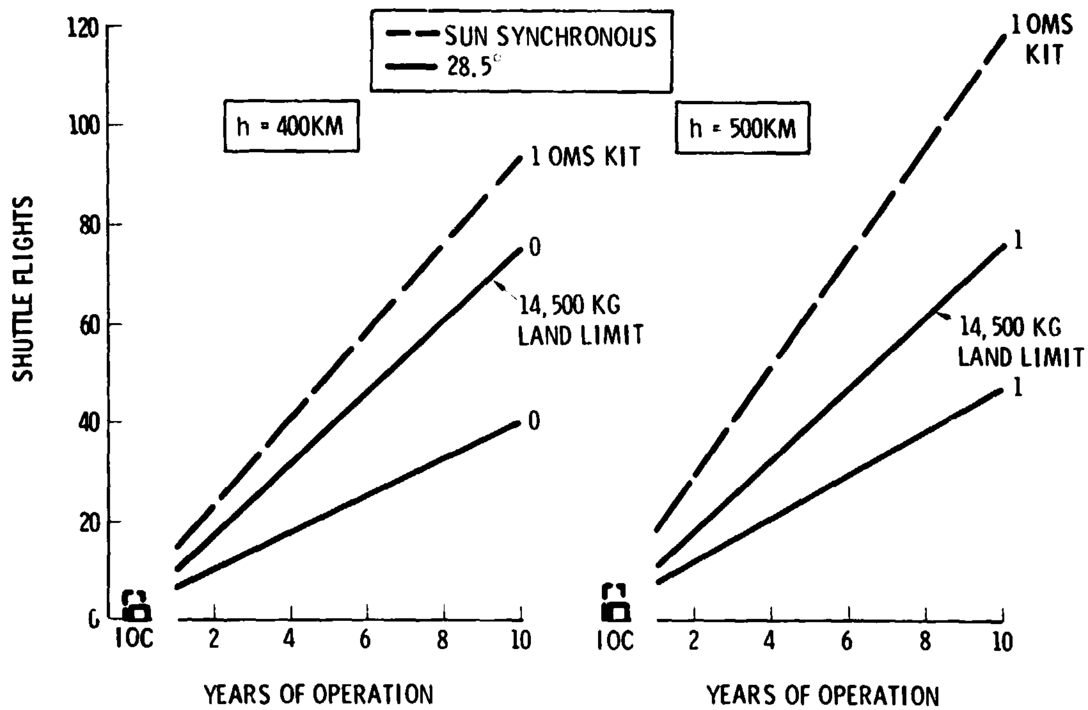

Figure 7-15. Commercial Processing Logistics

The power system cost for a 28.5-degree orbit was found from the equations below:

$$\text{Nonrecurring Cost (\$ million)} = 41.5\,(P)^{.5} + 52.2$$

$$\text{Recurring Cost (\$ million)} = \underbrace{2.79\,(P)}_{\text{Solar Array}} + \underbrace{3.32\,(P)^{.5}}_{\text{Storage/Distribution}}$$

For a sun-synchronous orbit, the size needed would be reduced by 1.8 while maintaining the same power output. The 1.8 factor includes 1.6 for continuous sunlight plus 0.2 for the removal of charging losses. In addition, the recurring storage/distribution system would be reduced since the night cycle storage batteries would be replaced by peaking batteries. A cost reduction of four was used for this term. The overall comparative power system costs are shown in Figure 7-16. At 100 kW, the differential is

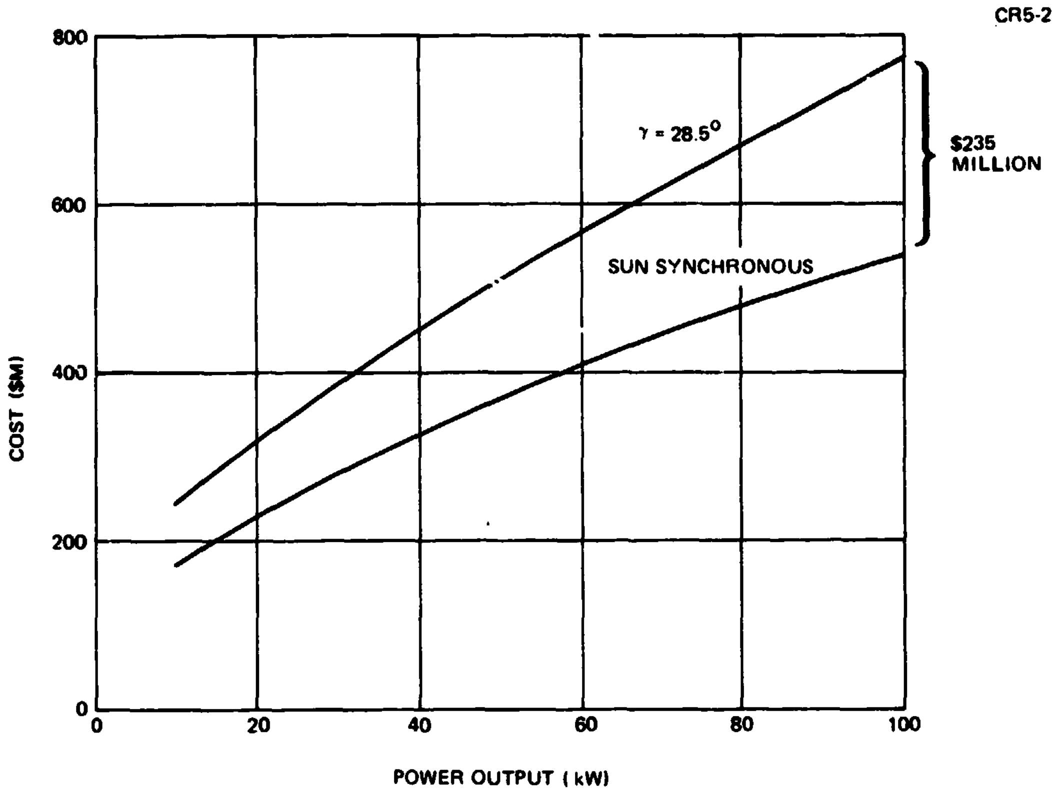

Figure 7-16. Power System Costs (NR+R)

$235 million. This cost differential from 28.5 degrees to sun synchronous as a function of power level is shown by the solid line in Figure 7-17. This can be compared to the cost increase due to increased Shuttle flights at sun synchronous at $19.1 million per flight shown by the dashed lines. The increase equals the decrease for an operating time of about 2 years. At that point, the operational cost at 28.5 degrees is the same as at sun synchronous. For longer operating times, the low inclination case would have a clear advantage as the logistics penalty keeps on accruing.

These data are shown for a 500-km altitude orbit, which is a reasonable selection for a long-term system. At 400 km, the operating time breakpoint would be 6 years, at which time, the cost of operating at the two inclinations would be equivalent.

If the Shuttle landing limit could be increased, the low inclination location would have a much greater advantage since the larger logistics capability at

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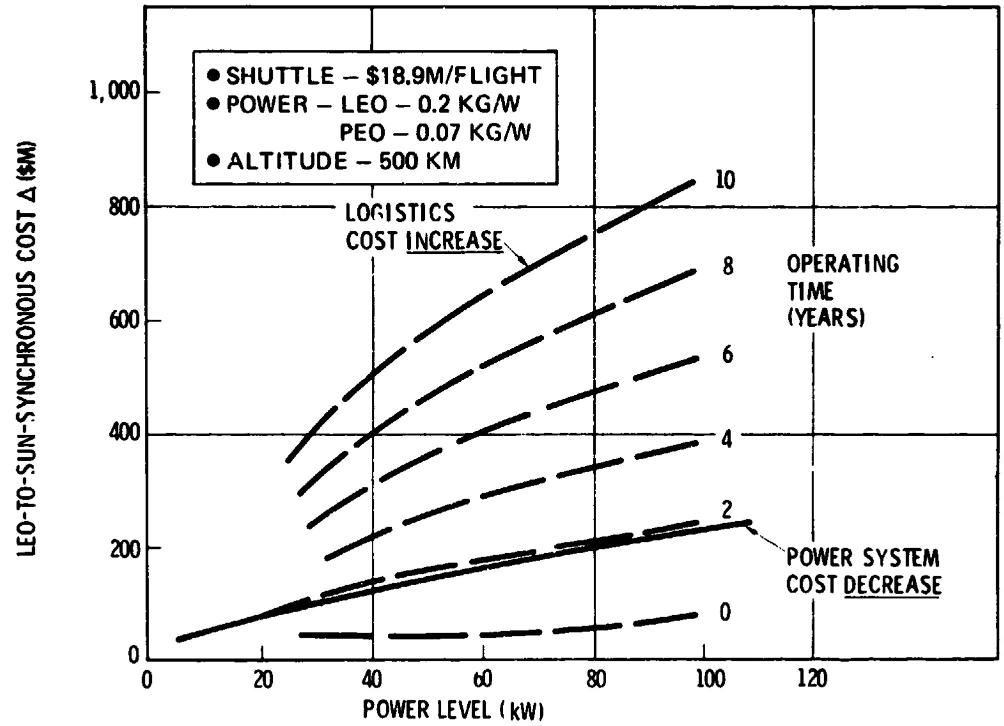

Figure 7-17. Processing Orbit Regime Cost Differential

low inclination could be used to advantage. Based on economics, it appears that low inclination would be preferred for the space processing system identified. Other influencing advantages that would accrue would be maintaining a KSC launch site, simpler logistics, and easier transport to GEO.

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Section 8
PROGRAMMATICS

This section presents the summary cost and schedule information for the permanently manned option (Option L) concepts, and the Shuttle-tended option (Option L') concepts that were developed in Part 3 of the SSSAS. These data are presented according to the approved work breakdown structure (WBS), which is defined in detail in the Part 2 WBS Dictionary (an appendix volume in the Part 2 SSSAS documentation). More detailed cost and schedule information may be found in Volume 3, Book 3 of the SSSAS Part 2 Final Report.

The following ground rules apply to the cost and schedule estimates:

1. Cost estimates are reported in constant mid-fiscal year (April) 1977 dollars.
2. When required, previous-year dollars will be escalated by using DOD price escalation factors and DCA price level indices.
3. Funding distributions will be in October 1 through September 30 fiscal years.
4. Cost estimates will be developed in consonance with the latest NASA/JSC approved WBS and WBS dictionary.
5. Cost estimates will be commensurate with program definitions at the time of the estimate and the relative level of study effort, and with the understanding that the estimates are only for preliminary planning and tradeoff study purposes.
6. The cost estimates will assume no dedicated flight-test hardware.
7. The cost estimates for the study are derived from three sources of information. Transportation costs (vehicle and flight costs) are furnished by NASA. Other hardware and programmatic costs are based on the costs reported in the Rockwell Phase B study. When hardware design is new or cannot be derived from the above Phase B source (by relocating hardware items or scaling key characteristics), MDAC estimates the costs using information in the MDAC data bank. In the latter case, programmatic factors derived from the above Phase B study will be applied to the MDAC hardware estimate.

8. Total program cost estimates exclude costs of experiment test hardware items (instruments, etc.), experiment operations, and experiment integration.
9. Cost estimates exclude the NASA institutional costs such as base support contractor personnel costs, civil service personnel salaries and allowances, and administrative support technical services.
10. No prime contractor fee is included in cost estimates. Subcontractor fees are included for all purchased items.
11. Shuttle launch costs are assumed to be $19.1M in Fiscal Year 1977 dollars per flight.
12. Flight crew costs are excluded from the total program costs.
13. Cost estimates assume that all hardware DDT&E and production effort will be allocated to contractor(s) in a manner that minimizes duplication of costs and maximizes the benefits of commonality.
14. The cost estimates will assume that the combined effort required by this program and other activities will be sufficient to permit each contractor to establish a sufficient labor base to operate in an efficient, controlled overhead environment.
15. The cost estimates do not include GFE.
16. Shuttle-tended option cost estimates do not include costs necessary to modify the Shuttle to meet the additional requirements of this mode of operation.
17. ATP is assumed to be 1 October 1979 with the first launch in December 1983. This allows a 51-month development program which, based on prior major programs experience, may be marginal.
18. The station buildup and activity during Shuttle-tended phase is based upon a launch every 30 days. Once the station is permanently manned, the required launches are 2 per year for the 7-man, 4 per year for the 14-man, and 6 per year for the 21-man station for logistics support.
19. First priority for objective elements accomplishment is given to space construction, second priority to space processing, and then to the other objective elements. Construction of TA2 is scheduled to be completed with as much testing as possible to support a 1987 SPS decision.

20. Construction activity is limited to one objective element at a time. Optimizing the use of the fabrication and assembly module builds the objective elements in series. However, there is testing of one objective element while the next one is being fabricated.
21. Best usage of EVA time resulted in an operation of two 10-hr shifts. Three shifts are used where feasible for other activities.

8.1 PERMANENTLY MANNED OPTIONS (OPTION L)

The permanently manned configuration (Option L) is shown in Figure 8-1 for two different crew sizes. This basic 7-man SCB configuration is capable of autonomous operation during both manned and unmanned periods, including all required docking and berthing ports, pressurized habitation and control facilities, power, and heat rejection capability. This SCB can grow to accommodate additional crew up to 21 men by adding extra modules. The basic 7-man SCB configuration (Figure 8-1) has the capability of supporting both fabrication and assembly of mission hardware plus space processing activities. The single power module supplies power up to 34 kW. The basic

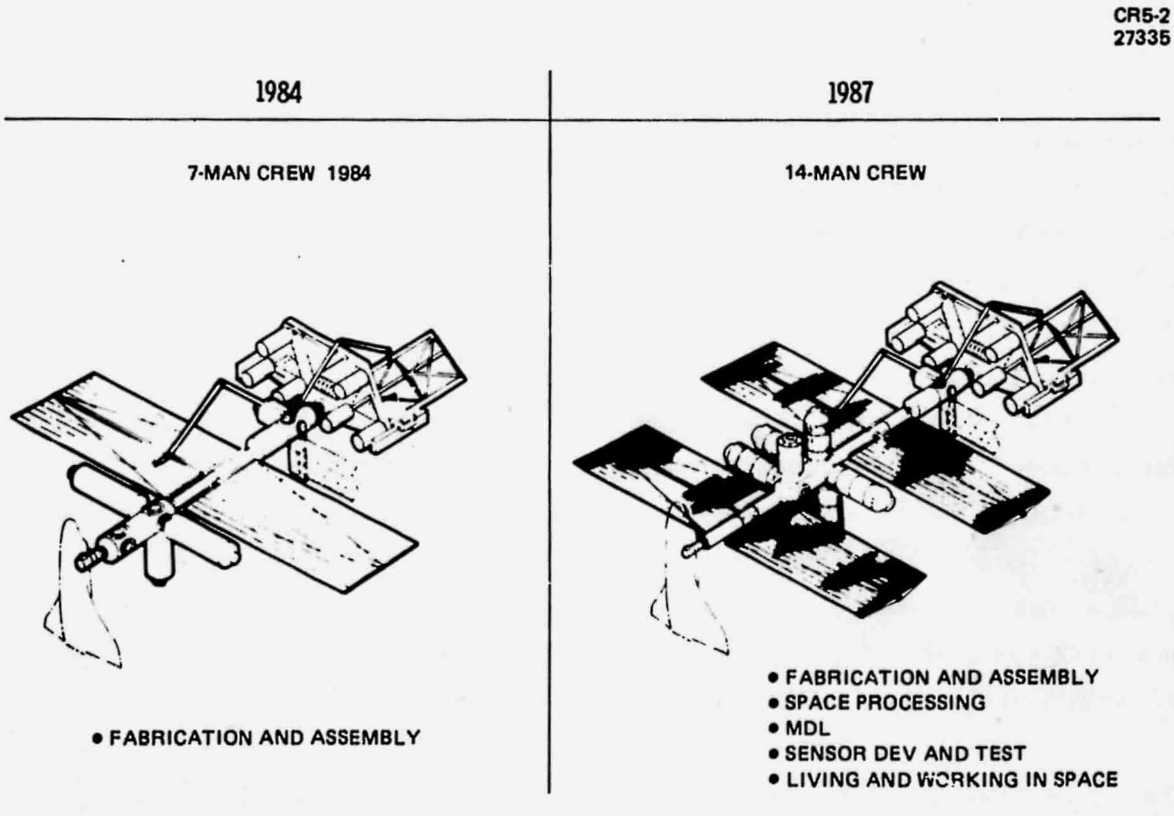

Figure 8-1. Option L SCB Configuration Evolution — Permanently Manned

elements of the SCB, in addition to the habitation elements, include the fabrication and assembly facility. This facility consists of the space construction support module, mobile crane, composite tube fabrication module, universal truss assembly jig, and solar collector fabrication and assembly jig. Following deployment of the fabrication and assembly facility tooling, the objective elements can be installed.

SCB growth in capability and size with time is illustrated in Figure 8-1 by the 14-man configuration. In this operational mode, several objectives can be simultaneously conducted with the subsequent increase in power requirements to 70 kW, which requires a second power module. A second habitation module is also needed for the additional crew. In addition to the aforementioned fabrication and assembly capabilities and space processing, the 14-man configuration can accommodate a multidiscipline science laboratory and sensor development facility, which also provides living and working in space experiments. Further growth to a 21-man crew can be accommodated by adding one more habitation module.

The schedule for the 7-man configuration is shown in Figure 8-2. The development is assumed to start in CY 1979 (FY 1980) with the first launch in December 1983. This development schedule is slightly more optimistic in comparison to the old phase B schedules, but is not considered unreasonable for planning purposes. This allows the SCB to be operational in mid 1984. The two SPS test articles, TA-1 and TA-2, are constructed first, followed by the 30m Radiometer Antenna. After this the Space Processing objective elements are accomplished followed by the multidiscipline lab, sensor development, and living and working in space objectives. The rate at which the nonconstruction objectives can be addressed is a function of the crew size (see Section 5.3). This causes the schedule for the completion of the 7-man option to be long. When the crew size is increased, the objectives may be done more quickly. This may be seen by examination of Figures 8-3 and 8-4, which shows the schedule for the 14- and 21-man SCB. In general, the increased crew allow the items to be accomplished more in parallel, thus decreasing the time to complete the total complement of items.

The cost estimates to develop, produce, place in orbit, and operate the 7-man permanently manned SCB station elements are given in Figures 8-5 and

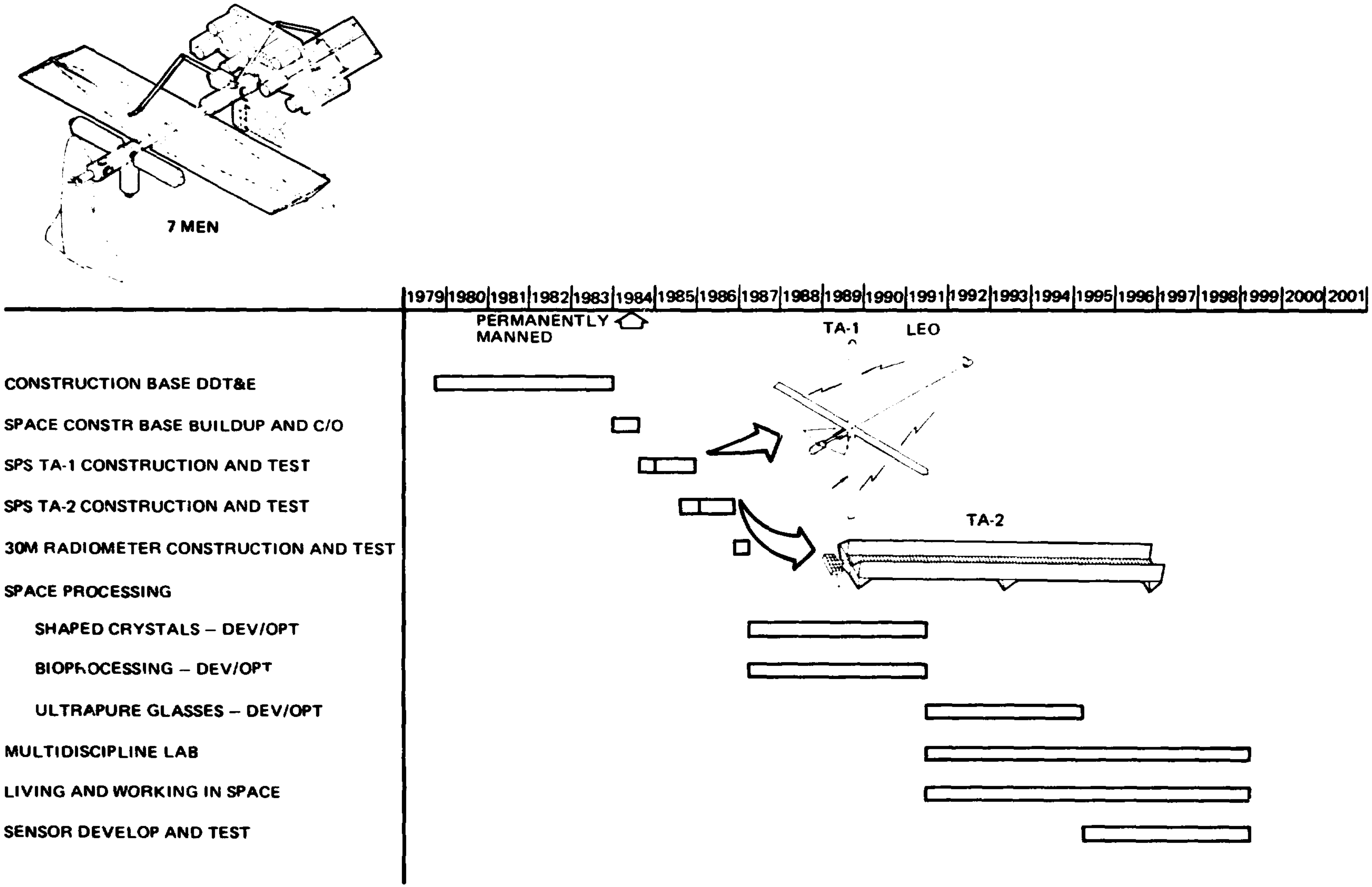

Figure 8-2.
Schedule for Permanently Manned Option, 7-Man Crew

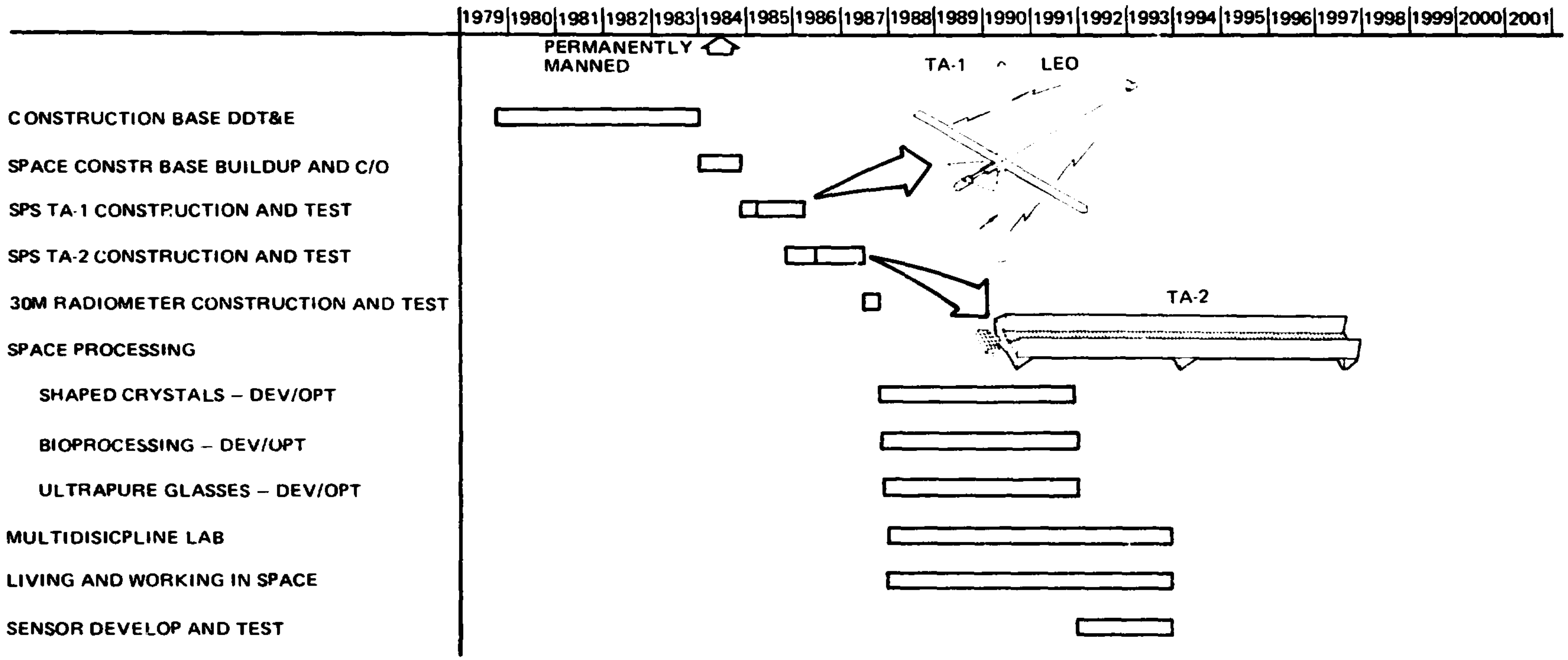

Figure 8-3.
Schedule for Permanently Manned Option, 14-Man Crew

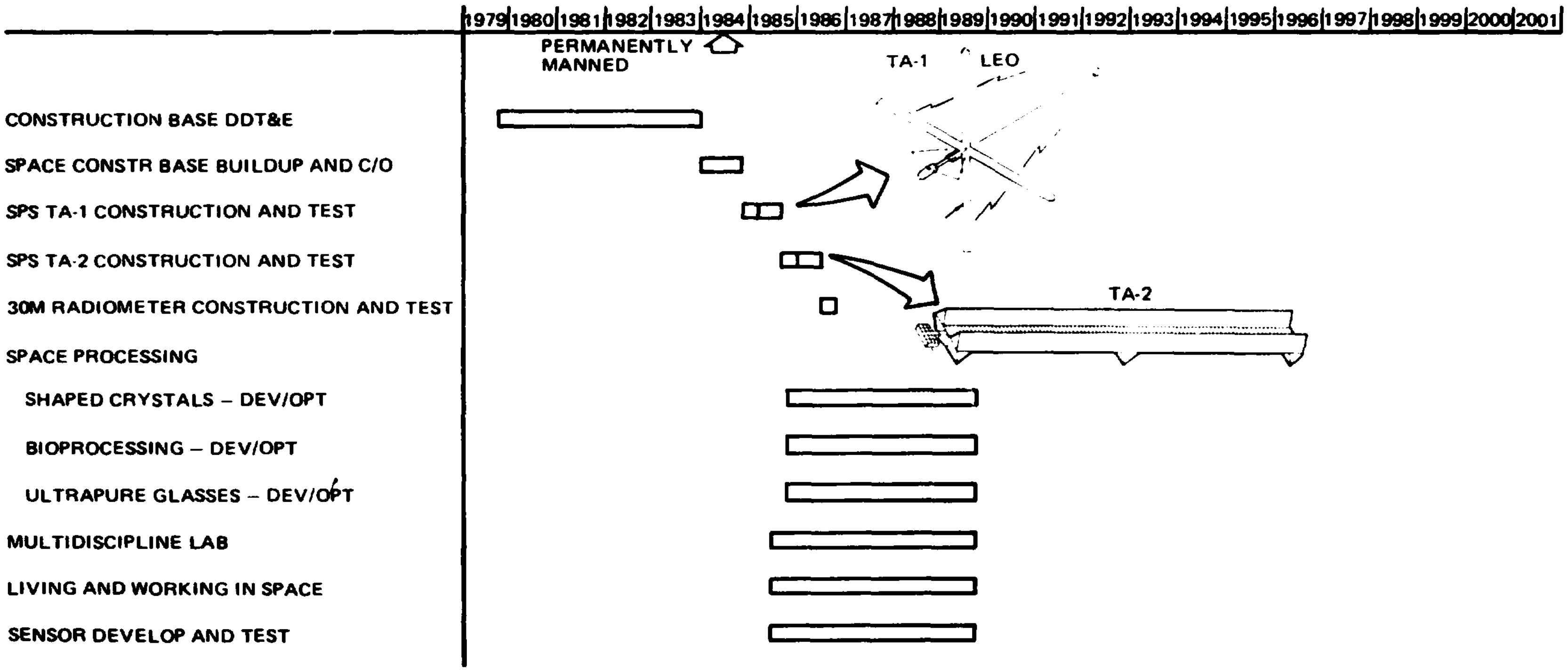

Figure 8-4. Schedule for Permanently Manned Option, 21-Man Crew

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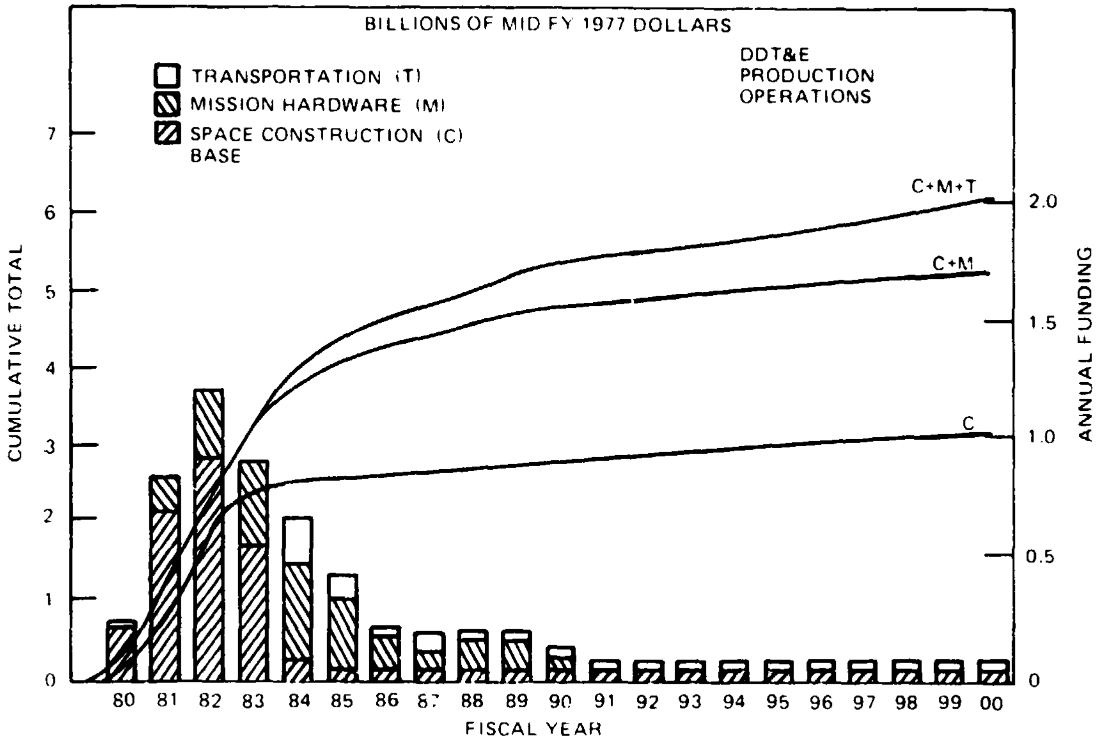

Figure 8-5. Permanently Manned Option Cost

8-6. Figure 8-5 presents the yearly funding requirements and cumulative cost segregated by major element, SCB, mission hardware, and transportation. Figure 8-6 presents a breakdown of the cost for each of the three major elements. The SCB is broken down to show the cost of the individual modules that comprise the SCB, and the cost of management and integration, ground test and GSE, and ground support during the operational period. The mission hardware is broken down to show the cost of the individual objective elements. The transportation cost is divided to show the cost required for implacing the SCB and mission hardware into orbit, and the logistics transportation cost for the operational period. Table 8-1 shows the effect of crew size on the cost to accomplish the program. The additional crew adds cost to the SCB because additional modules must be added to support the additional crew, but reduces the SCB support costs because the total program duration is shorter with the larger crew. The total effect on SCB cost depends on the relative magnitude of these two factors. Starting with the 7-man case as the base, to accommodate 14 men, a power module and a habitation module must be added. A further increase to 21 men requires another habitation module

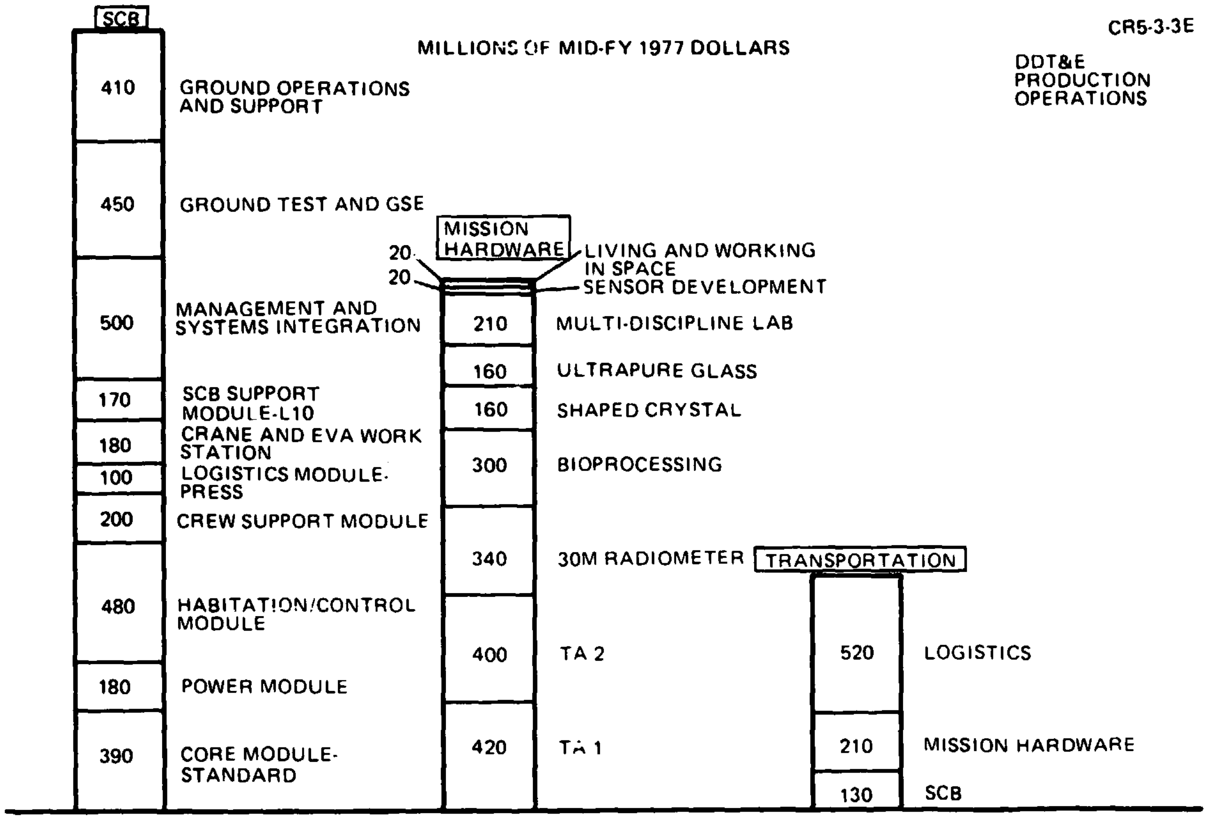

Figure 8-6. Permanently Manned Cost Breakdown

Table 8-1

COST COMPARISON—PERMANENTLY MANNED SCB
WITH DIFFERENT CREW SIZE

SCB Crew Size	SCB Cost	Mission Hardware Cost	Transportation Cost	Total Cost
7	3,060	2,030	860	5,950
14	3,050	2,030	880	5,960
21	3,170	2,030	860	6,060

Cost in $Millions
Includes DDT&E, Production, and Operations

and a short core module to provide addition berthing space. The reduction in program duration can be seen on the schedules (Figures 8-2, 8-3, and 8-4).

8.2 SHUTTLE-TENDED STRONGBACK OPTION (OPTION L'_6)

To understand the cost data that is presented for the Shuttle-tended option, it is important to keep in mind that these options are accomplished in two phases. First, a Shuttle-tended phase is used for about 1-1/2 years, during which time TA-1 and the 30m radiometer are constructed and tested. During this phase, the SCB is not autonomous but must rely on the Shuttle, whenever the SCB is manned, for habitability and many other functions. Then the SCB is expanded to provide the capability to support the crew autonomously with the Shuttle providing only logistics support on a 90-day cycle.

The configuration of the Strongback Shuttle Tended option is shown in Figures 8-7 and 8-8. Figure 8-7 is the SCB as it operates in the Shuttle-tended portion of this option, and Figure 8-8 is the SCB after it grows to the permanently manned operation. This version of the Shuttle-tended concept, the Strongback, is relatively austere compared to the other Shuttle-tended cases. It consists of only a rudimentary fabrication and assembly module, using a Shuttle-derived remote manipulator system (RMS), and it relies to a maximum extent on the Shuttle vehicle for habitability, power, stability and control, communications, and data management. Only enough independent capability is provided on the Strongback to preserve the hardware in-between Shuttle visits, and to permit Shuttle rendezvous and redocking.

The growth to a permanently manned SCB is accomplished by the addition of modules to provide the capability for autonomous, manned operations of long duration. Only a few of the original strongback components are used in the growth configuration for this option. A complete description of the strongback design may be found in Section 5.3.4.

The schedule for the Shuttle-tended strongback option is given in Figure 8-9. This starts out with a crew of 4 men in the Shuttle-tended mode through the completion of TA-1 and the 30m radiometer. The growth to the permanently manned configuration then takes place which has a 7-man crew. TA-2 is

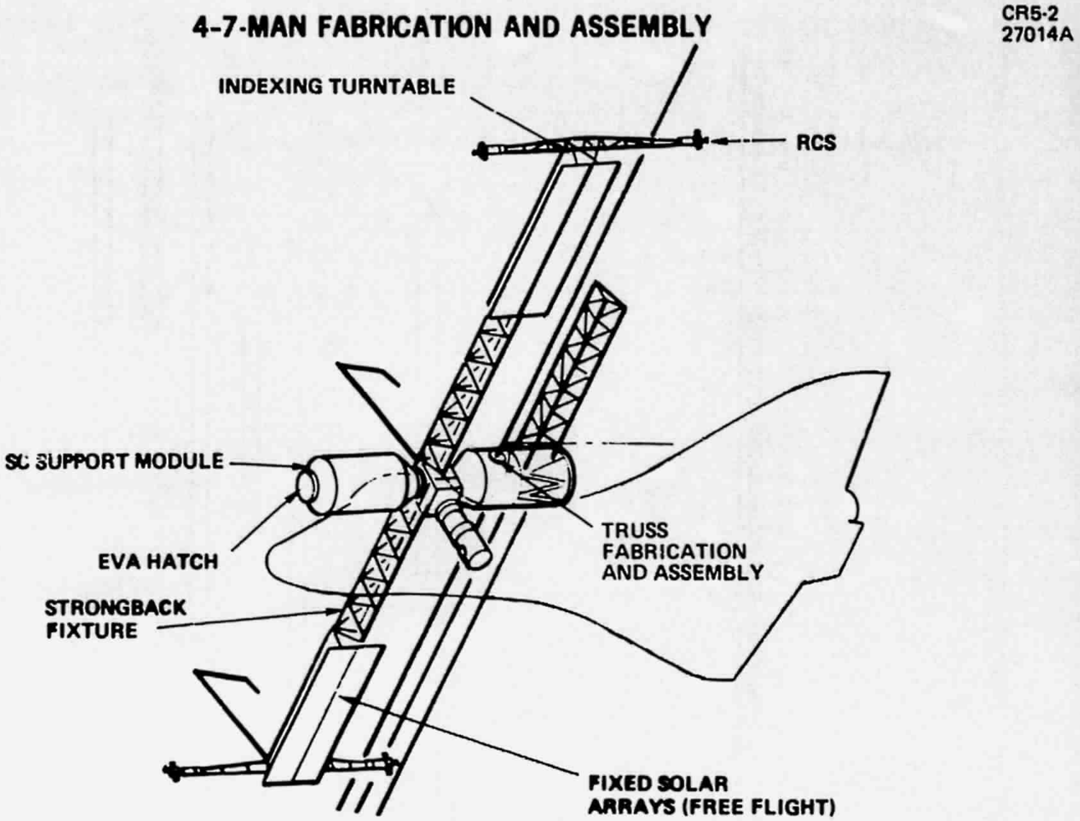

Figure 8-7. Shuttle-Tended SCB Option L' – Strongback

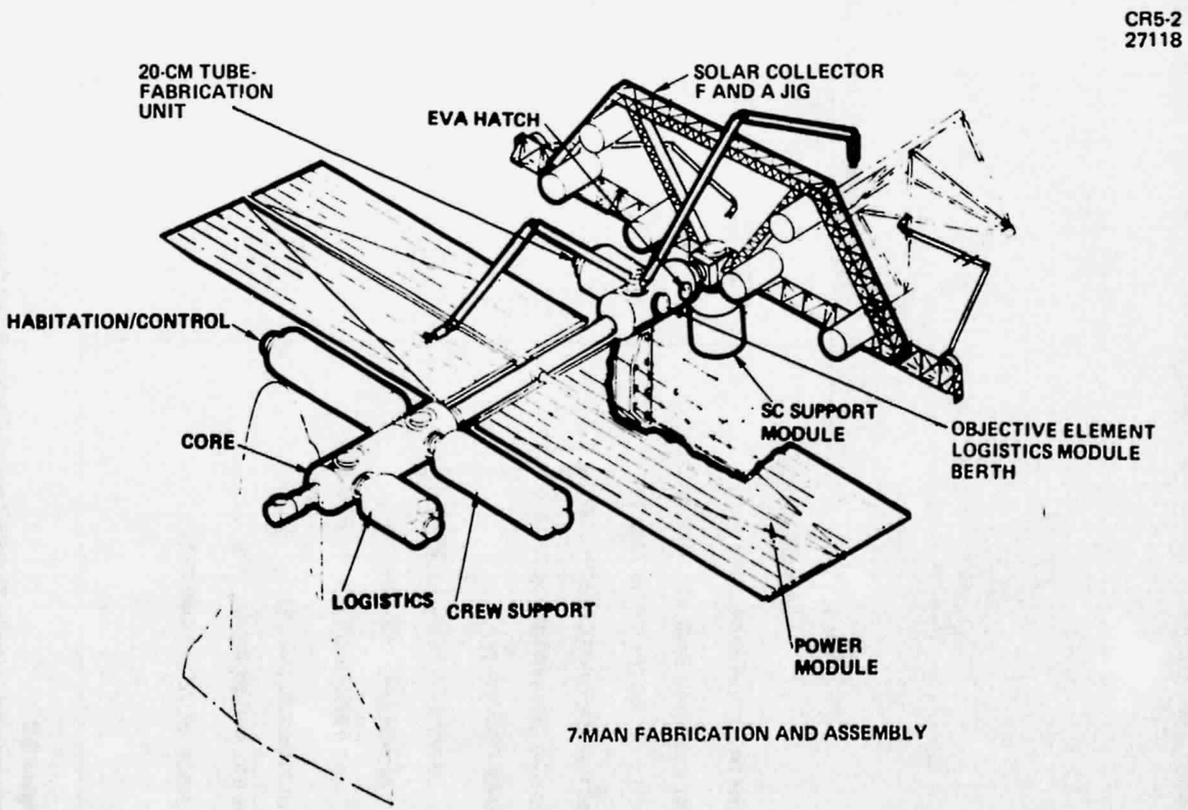

Figure 8-8. Option L Permanently Manned SCB – Strongback

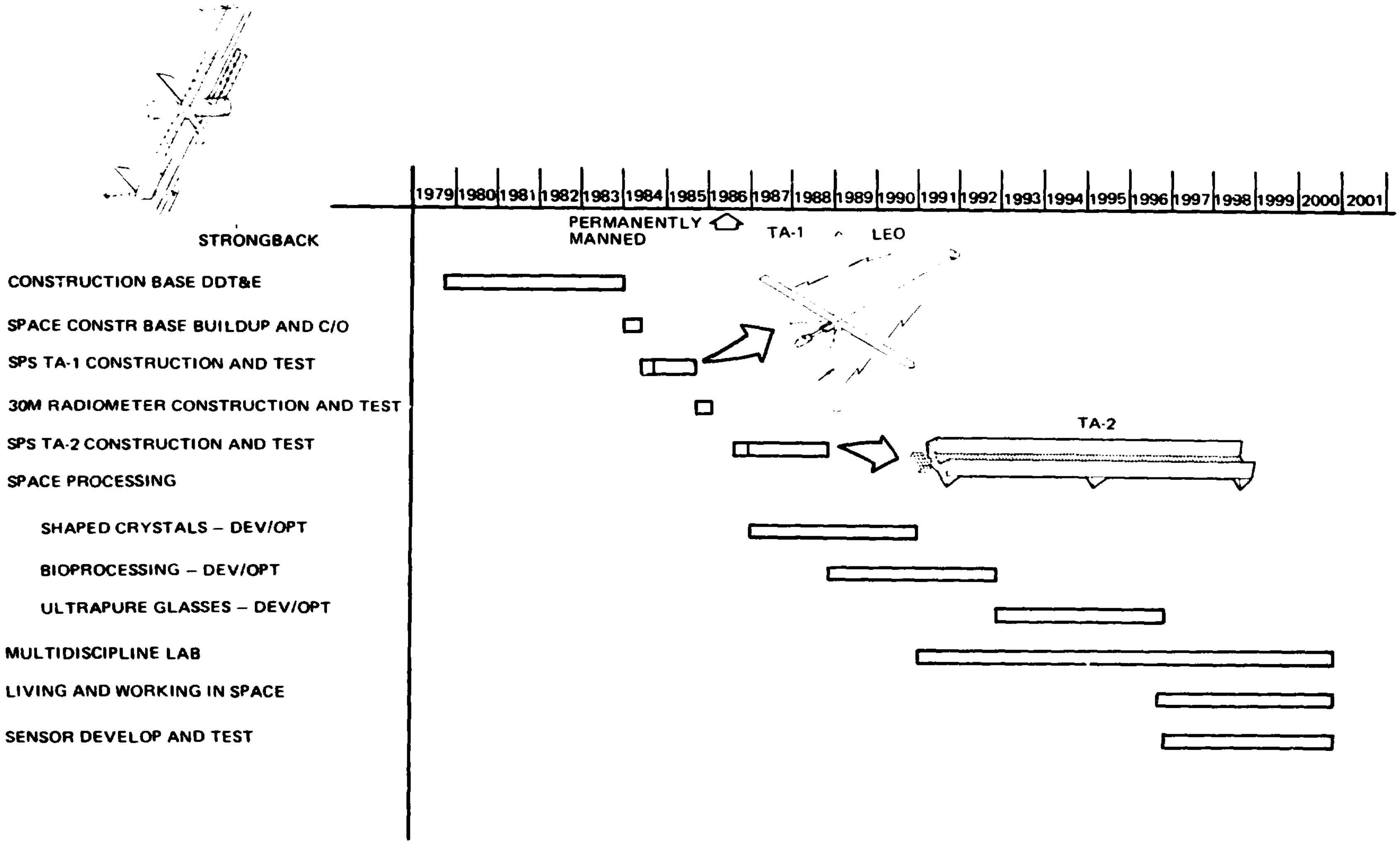

Figure 8-9.
Schedule for Initially Shuttle-Tended Option, Strongback

then completed, followed by the space processing, multidiscipline lab, and other objectives. Because of the 7-man crew the completion of all objectives extends the program quite long. This could be remedied by providing capability for additional crew when the SCB grew into a permanently manned configuration. The effect of crew size on schedule can be seen by examination of Figures 8-2, 8-3 and 8-4.

The cost estimates for the Shuttle-tended strongback options are given in Figures 8-10, 8-11, 8-12, and 8-13. Figures 8-10 and 8-11 present the cost data for the Shuttle-tended portion of the option, and Figures 8-12 and 8-13 present the total cost for this option (including both Shuttle-tended and permanently manned portions). In each pair of figures the first figure gives the annual funding requirements by fiscal year and the cumulative cost, and the second figure presents the breakdown of the cost by major WBS and hardware element.

By comparing the annual funding on Figure 8-12 with that of Figure 8-5 (the permanently manned option), a major advantage of the Shuttle-tended approach can be seen; namely, a reduction in the annual funding required during the early part of the program. This reduction results from the fact that since the Shuttle-tended portion of the option is done first, this allows the schedule for the development of the permanently manned elements to slip with a consequent delay in the relatively high funding required for these developments. This reduction in early year funding holds true for the other Shuttle-tended cases as well, although the magnitude varies somewhat with each program option. However, the cost for the total option (Shuttle-tended and growth to permanently manned) is higher than for the options that are only permanently manned. The reasons for this will be discussed in detail in Section 8.5.

Another interesting feature of the Shuttle-tended cases is the higher transportation costs associated with this mode. This is due to two factors which can be seen by comparing Figures 8-13 and 8-6. First, the cost of implacing the SCB in orbit is somewhat higher for the Shuttle-tended case because there are more total equipment to be placed in orbit. Secondly, the mission hardware transportation cost in the Shuttle-tended option is significantly greater because of the large number of Shuttle flights required when the

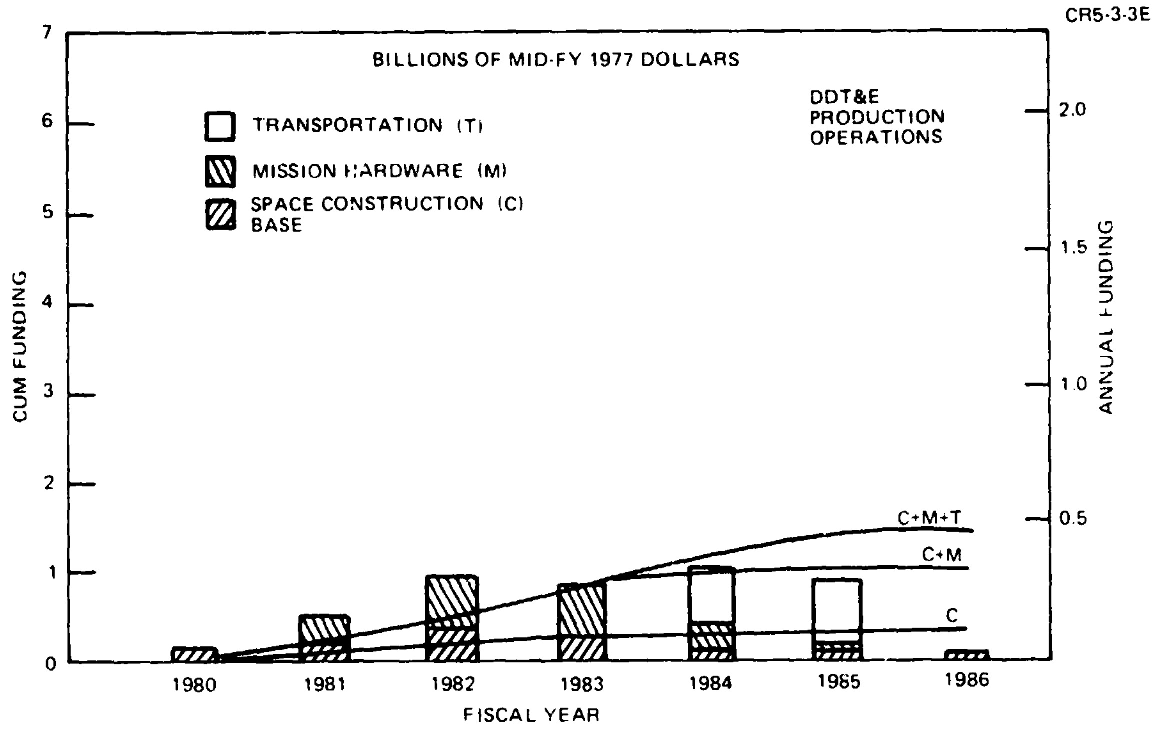

Figure 8-10. Strongback Shuttle-Tended Portion Cost

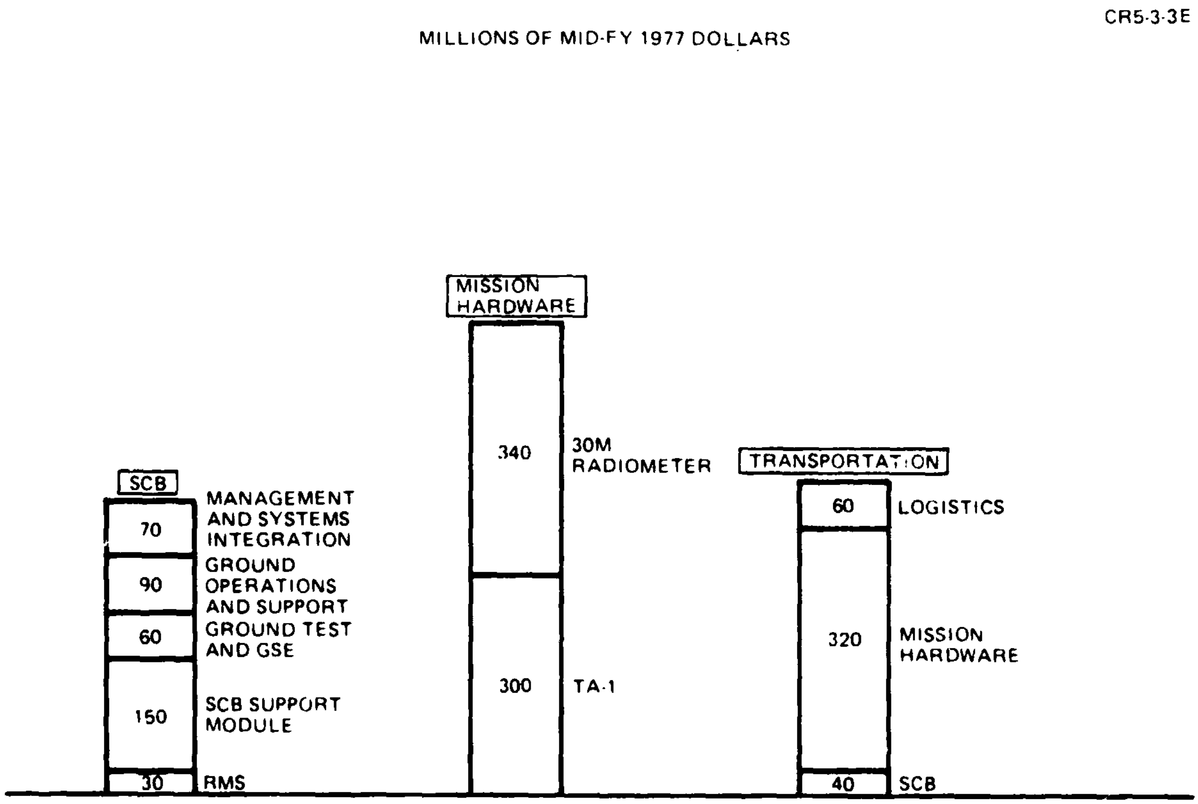

Figure 8-11. Strongback Shuttle-Tended Portion Cost Breakdown

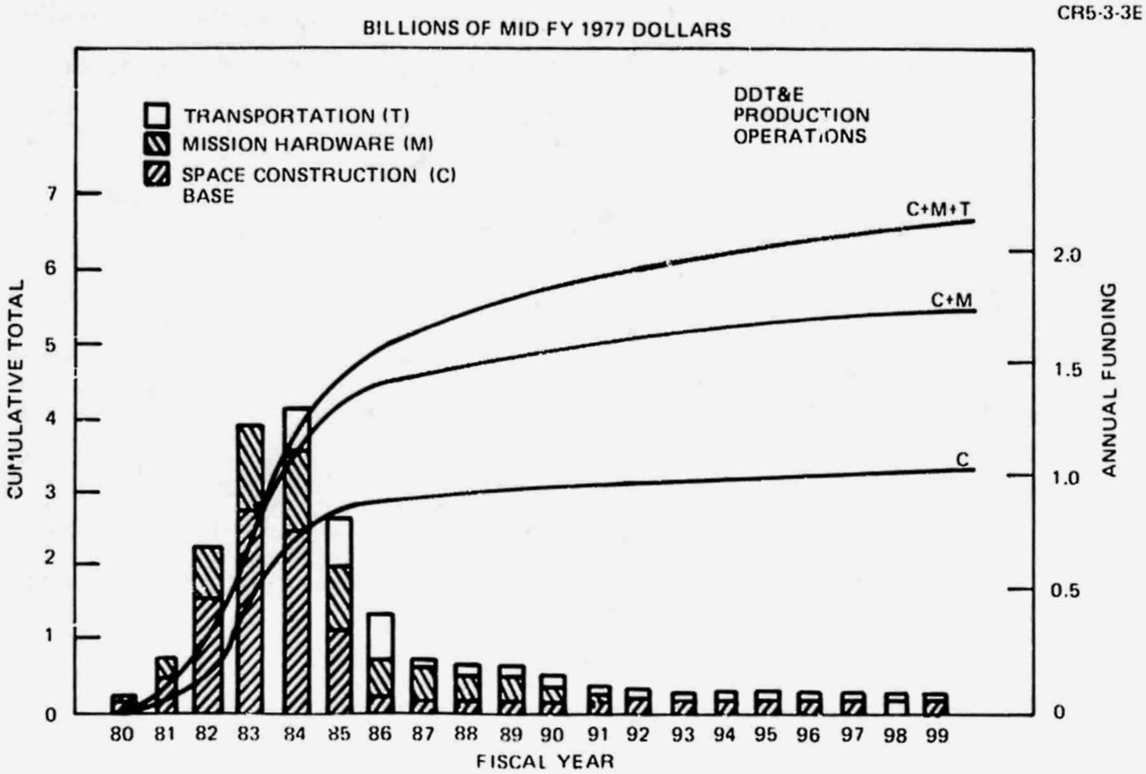

Figure 8-12. Strongback Option Cost

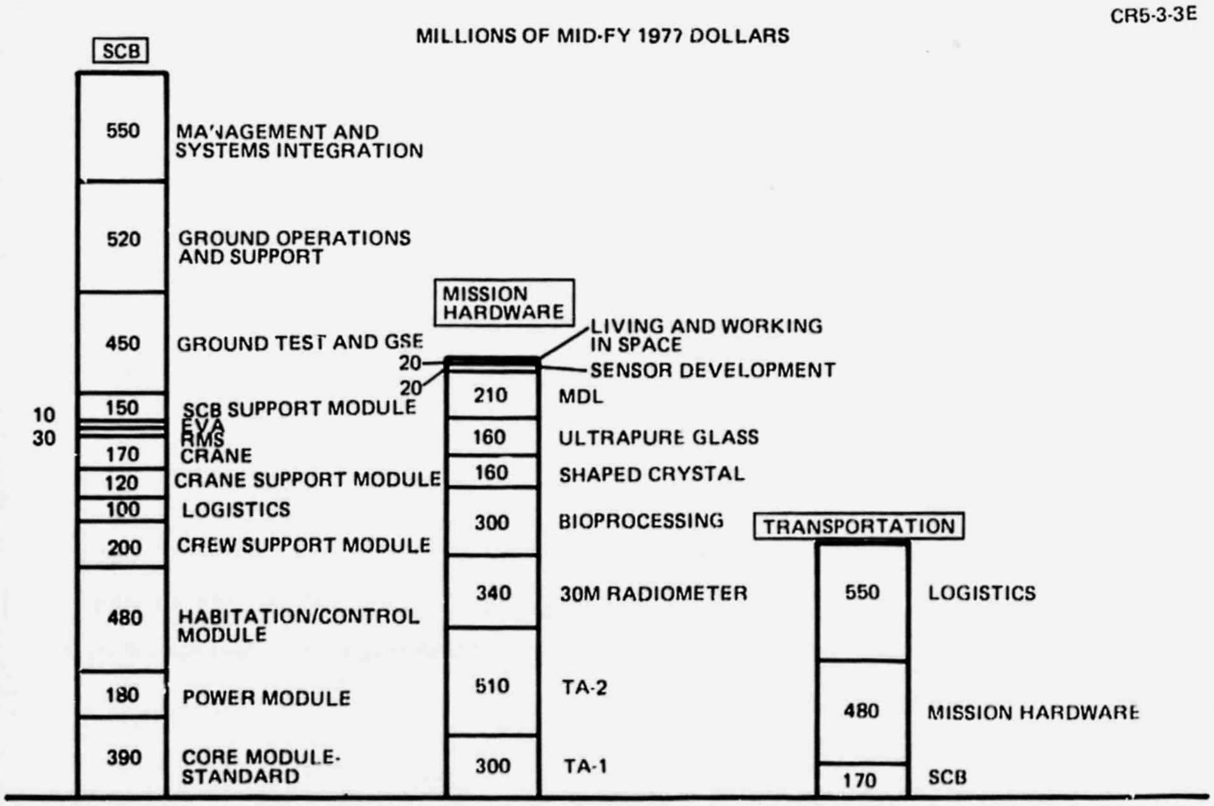

Figure 8-13. Strongback Cost Breakdown

Shuttle sortie mode is being used, i.e., one flight every 30 days. These features generally carry over to the other two Shuttle-tended cases, but to a lesser degree than for the strongback approach.

8.3 SHUTTLE-TENDED SINGLE LAUNCH OPTION (OPTION L'_8)

The configuration for the Shuttle-tended single launch option is given in Figures 8-14 and 8-15, where Figure 8-14 is the configuration used while in the Shuttle-tended mode, and Figure 8-15 is that for the growth or permanently manned portion of this option.

The Shuttle-tended configuration used here is more autonomous than that for the strongback previously discussed. The primary element is a support module which contains capabilities for electrical power, limited guidance and control, propulsion, communications, and crew EVA operations. Data management, internal atmosphere, thermal control, and crew life support systems are provided by the Orbiter. A two-arm manipulator mobile crane is used for material handling and construction operations. The development of a single-launch L' facility into the permanently manned SCB facility, Figure 8-15, is by the addition of modules to increase the functional capaccities for unattended orbital operations. Since this L' derivative concept started with the advanced long-reach crane and the all-up-4-man airlock, the primary add-on requirements are a large electrical power system and expanded permanent crew habitation and additional berthing capability.

The schedule for the single launch option is given in Figure 8-16, and is very similar to that of the strongback discussed in Section 8.2. During the Shuttle-tended portion of the operation a 7-man crew is used, which permits TA-1 and the 30m antenna to be completed somewhat earlier than for the strongback case.

Figures 8-17 through 8-20 present the yearly funding and cumulative costs for the single launch option. These data show the same general trends as the strongback case, but the cost difference when compared to the permanently manned option are not as great.

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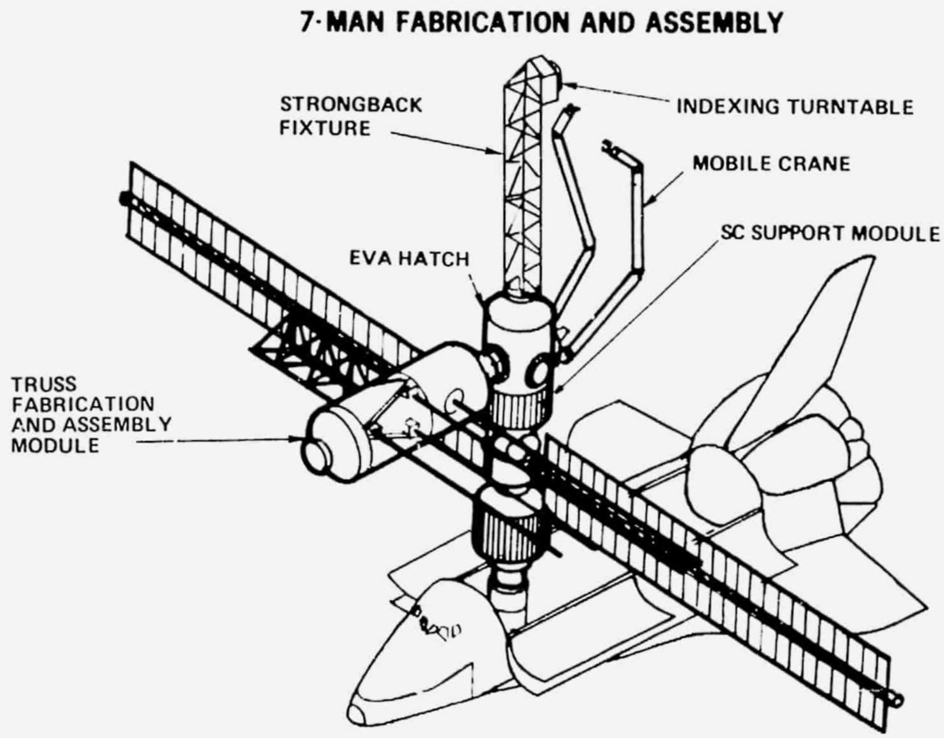

Figure 8-14. Option ' ' Shuttle-Tended SCB – Single-Shuttle Launch

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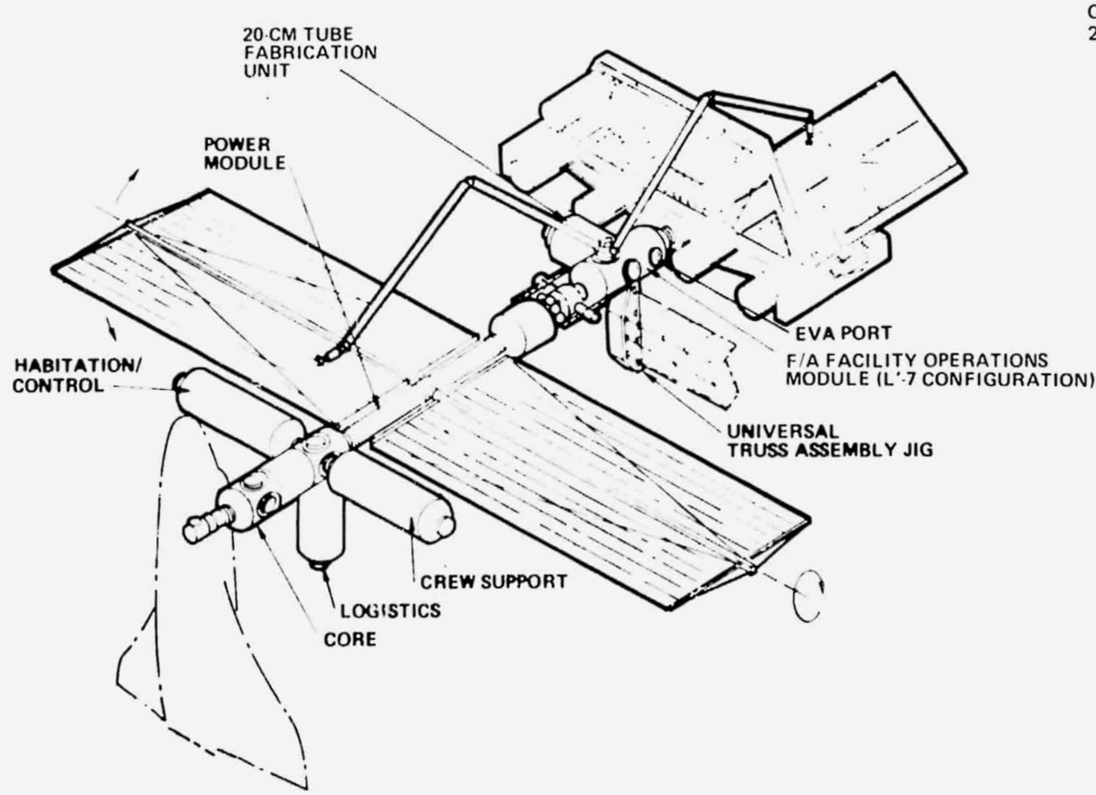

Figure 8-15. Option L Permanently Manned SCB – Single-Shuttle Launch

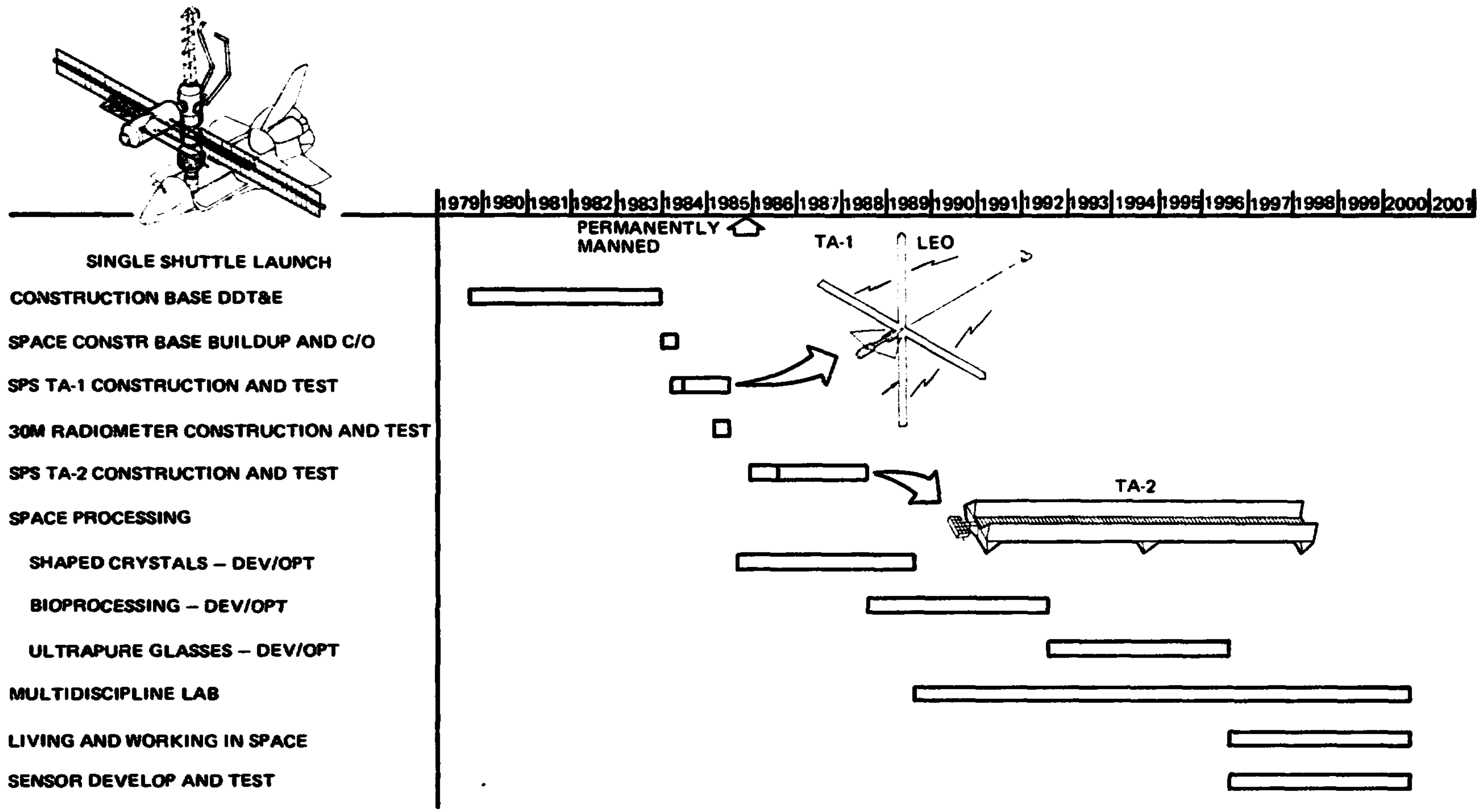

Figure 8-16.
Schedule for Initially Shuttle-Tended Option, Single-Shuttle Launch

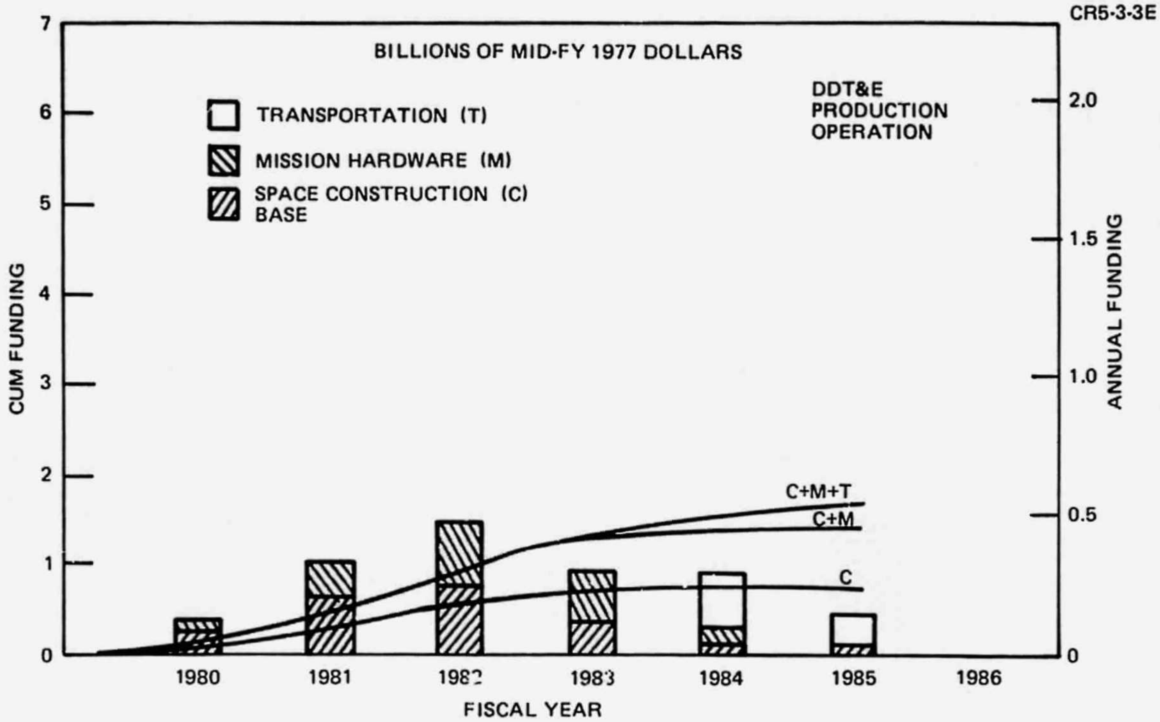

Figure 8-17. Single-Launch Option Shuttle-Tended Portion

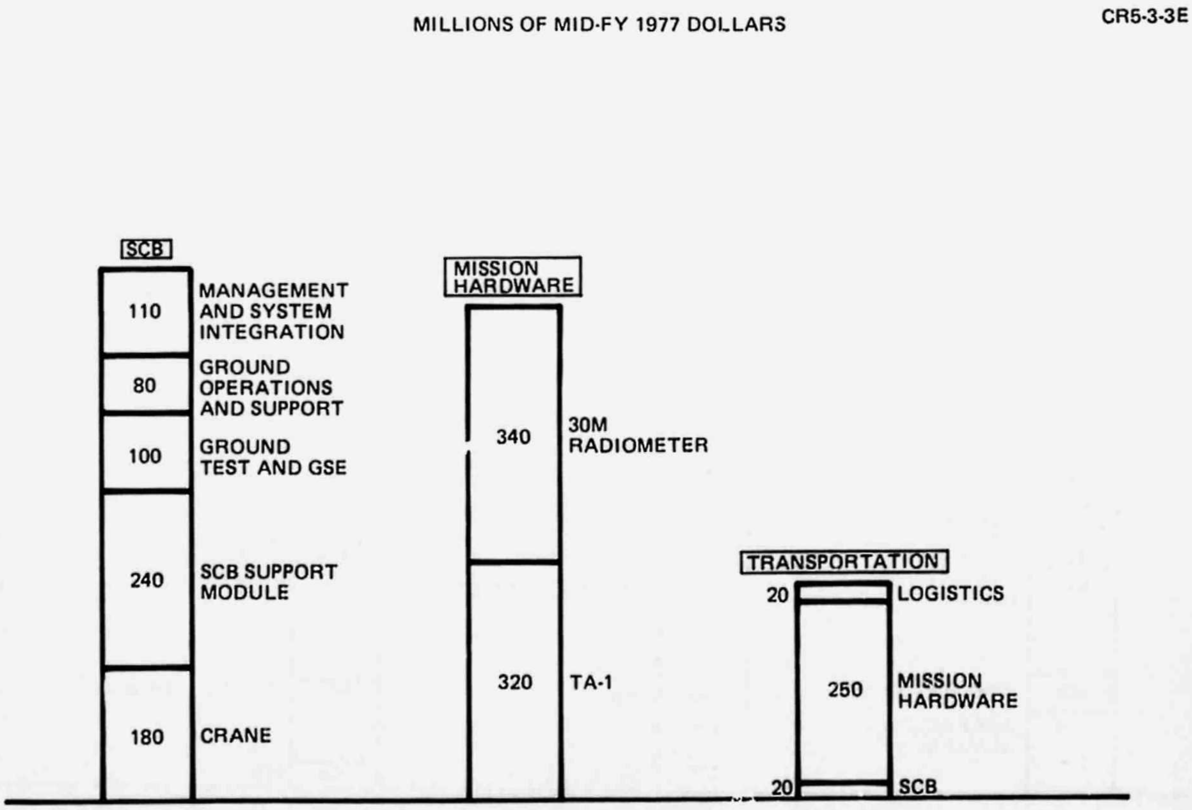

Figure 8-18. Single-Launch Shuttle-Tended Portion Cost Breakdown

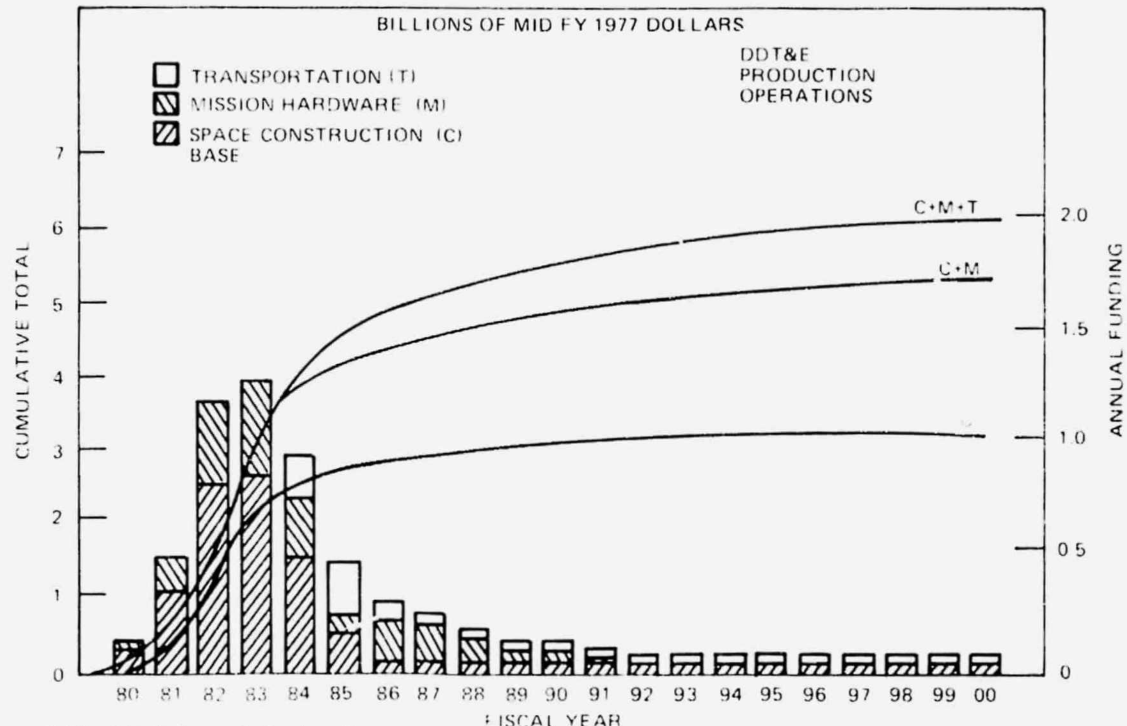

Figure 8-19. Single-Launch Option Cost

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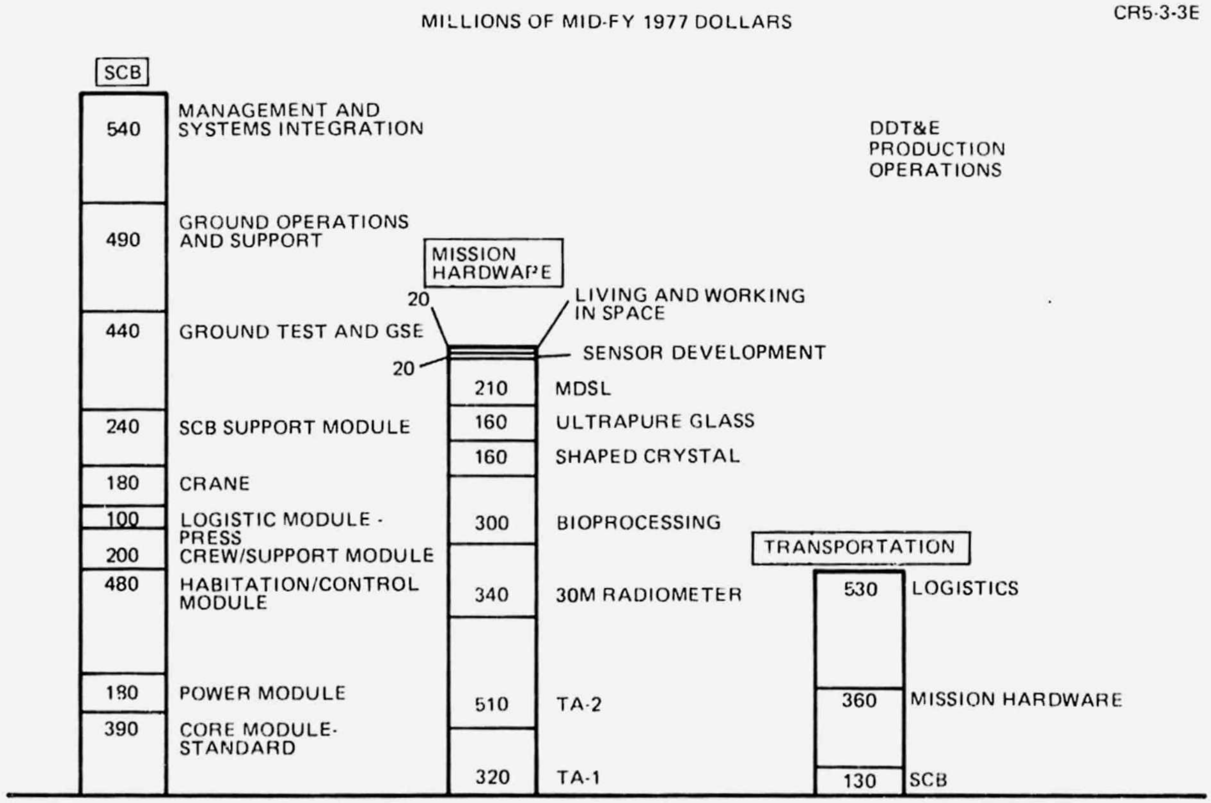

Figure 8-20. Single-Launch Option Cost Breakdown

8.4 SHUTTLE-TENDED DIRECT GROWTH OPTION (OPTION L'_{10})

The configurations used in this option are shown in Figures 8-21 and 8-22. For this option, the modules for the Shuttle-tended portion of the SCB are the same as those used during the permanently manned portion, except that the crew habitability and cargo functions are provided by the Shuttle. Therefore, this is the most autonomous of the Shuttle-tended configurations with inherent growth capability to the permanently manned configuration. When growth takes place, all that must be added are the two crew modules and a cargo module.

The schedule for this case is shown in Figure 8-23, and it is nearly identical to the single launch option just discussed. The direct growth facility accommodates a 7-man crew during both Shuttle-tended and permanently manned phases.

Figures 8-23 through 8-27 present the cost estimates for the direct growth option.

8.5 COMPARISON OF OPTION COST ESTIMATES

A cost comparison for all of the options is given in Table 8-2. The data are divided into SCB costs, mission hardware costs, transportation costs, and the total for each option. Each option is partitioned to show the costs associated with the Shuttle-tended mode of operation, and the total option cost including both the Shuttle-tended portion and the growth to a permanently manned configuration. In general, these data indicate that the Shuttle-tended configurations, while requiring a lesser investment during the Shuttle-tended portion of the operation, are more costly to complete the total program in comparison to the permanently manned option. This is largely due to two factors: (1) much of the SCB hardware that is put up during the Shuttle-tended portion of these options is not suitable for use during the permanently manned operation. Therefore, the total cost of the SCB is driven up by this duplication of hardware, (2) the transportation requirements during the Shuttle-tended period are high because of the sortie mode operation which requires a Shuttle flight every 30 days. The cost difference between the Shuttle-tended options (total with growth) and the permanently manned options is seen to get progressively smaller as the configuration for the Shuttle-tended portion

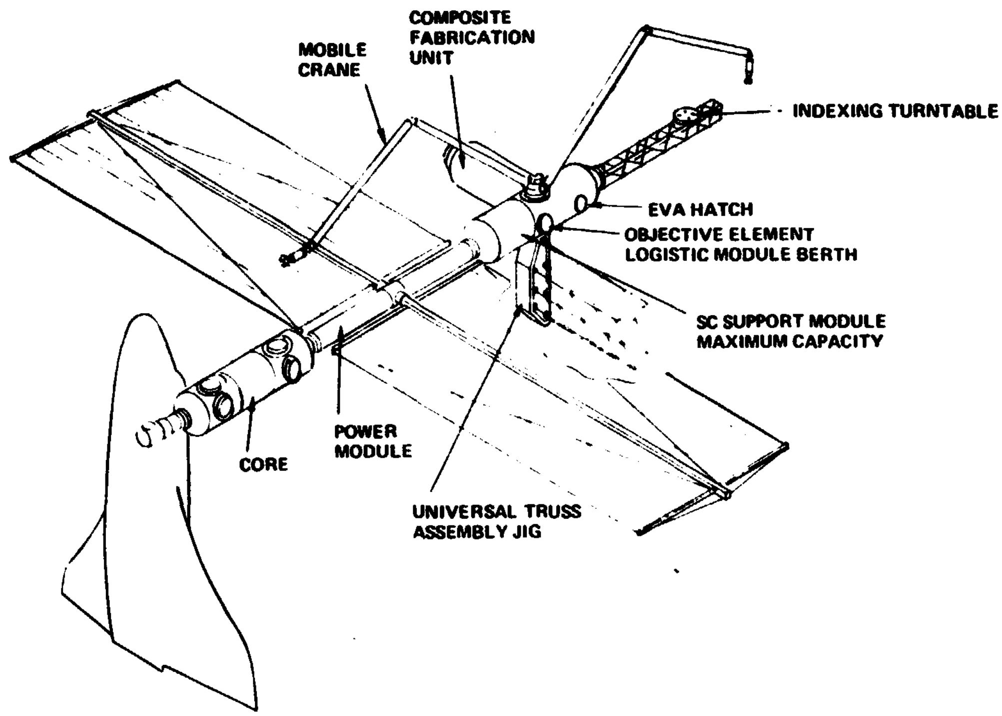

Figure 8-21. SCB (L') Shuttle Tended – Direct Growth

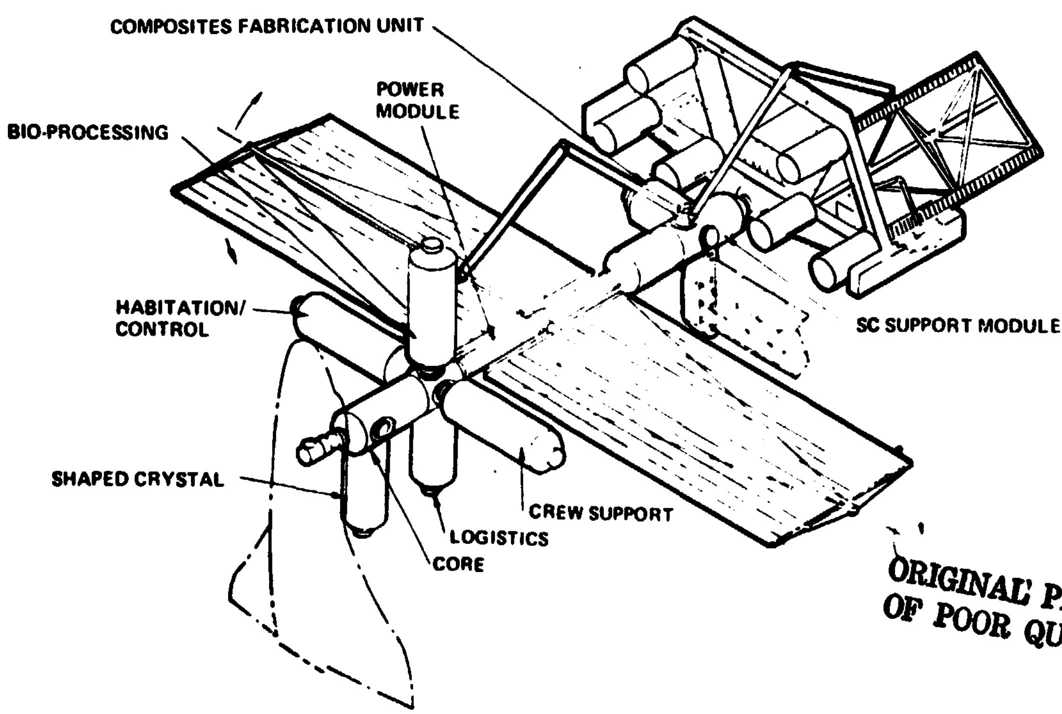

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Figure 8-22. SCB (L) Permanently Manned – Direct Growth

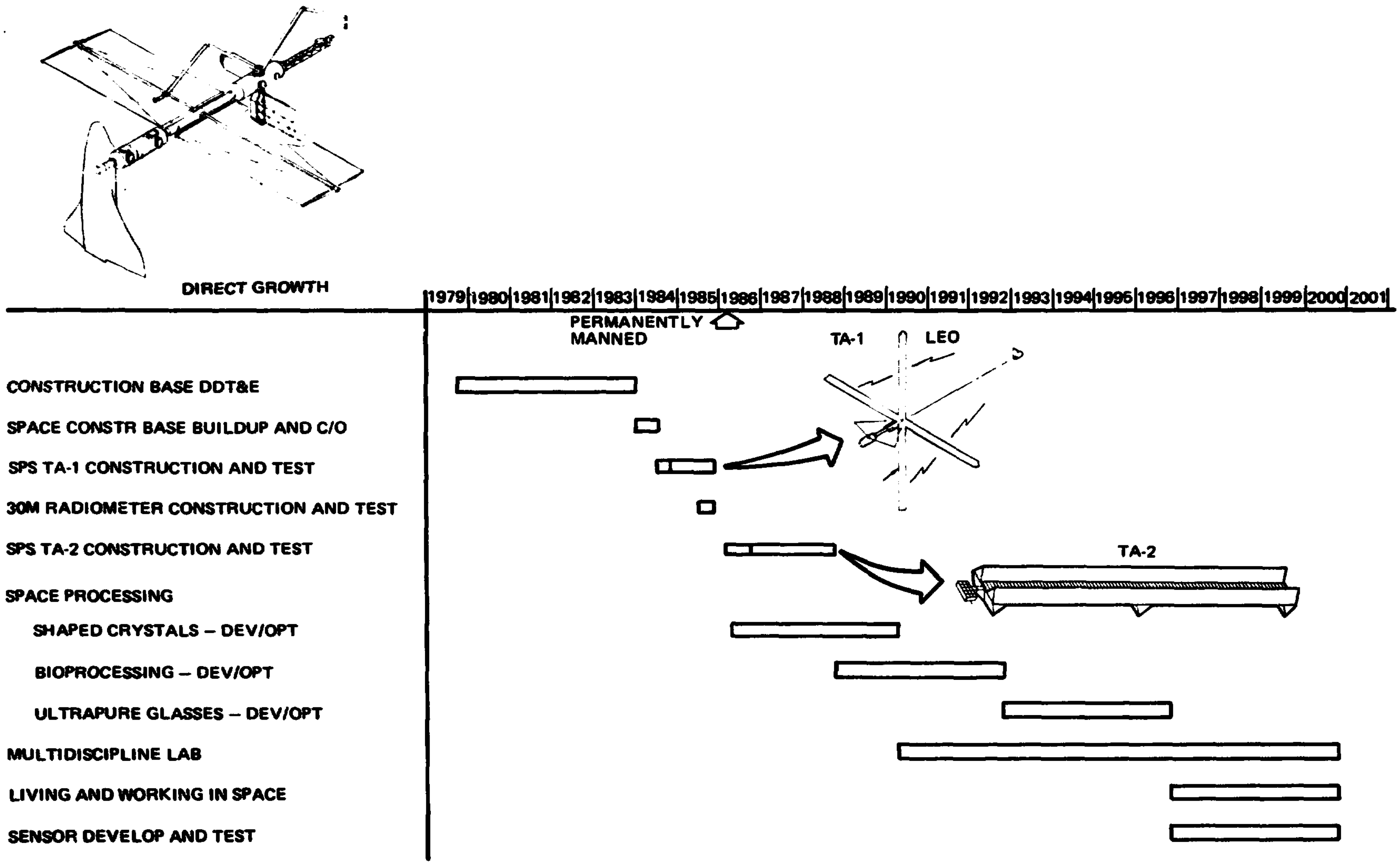

Figure 8-23.
Schedule for Initially Shuttle-Tended Option, Direct Growth

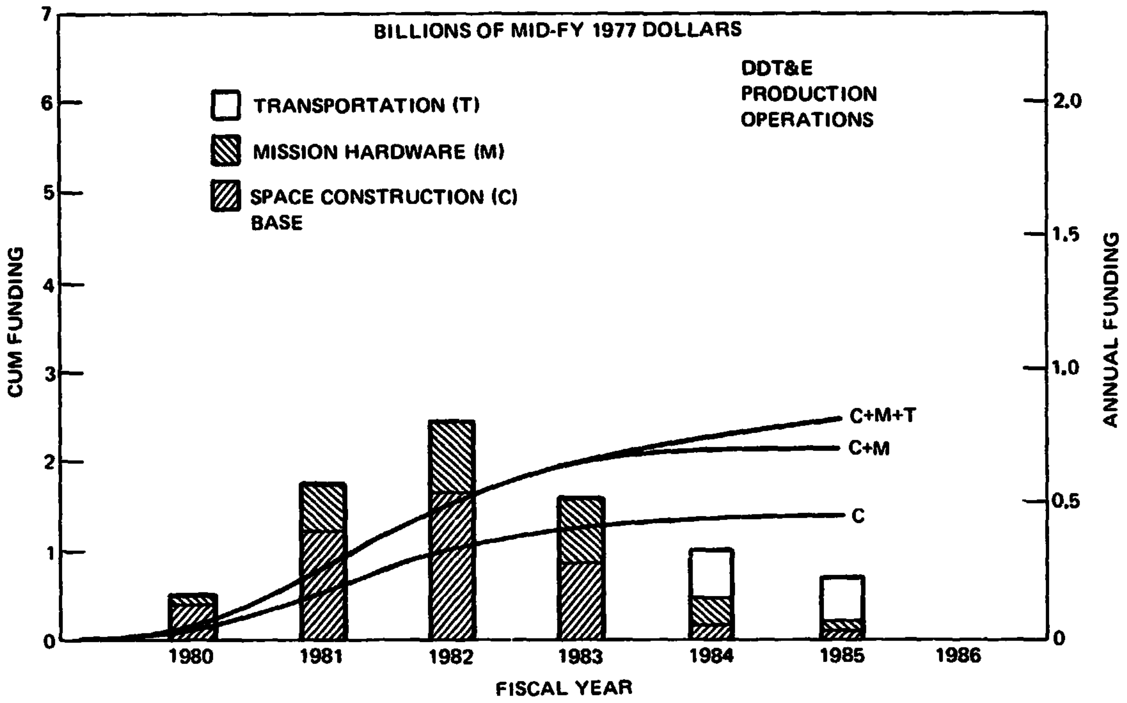

Figure 8-24. Direct-Growth Shuttle-Tended Portion Cost

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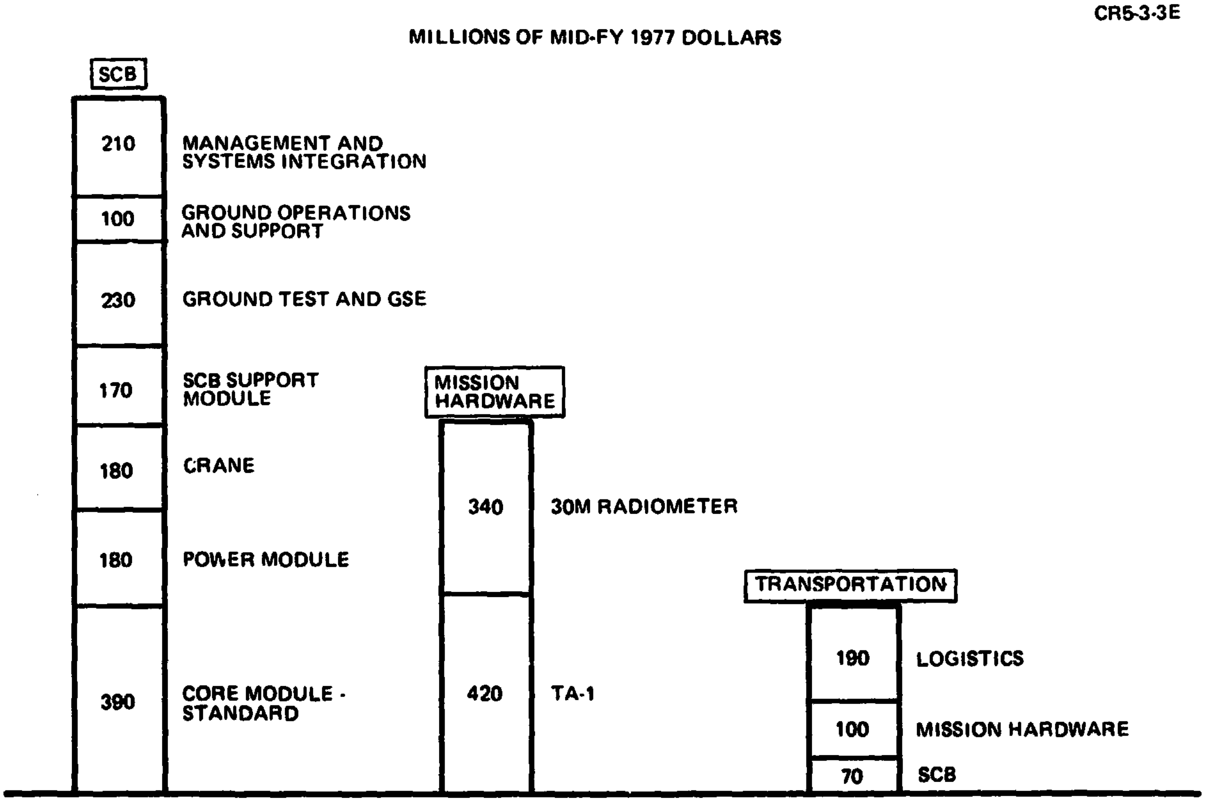

Figure 8-25. Direct-Growth Shuttle-Tended Portion Cost Breakdown

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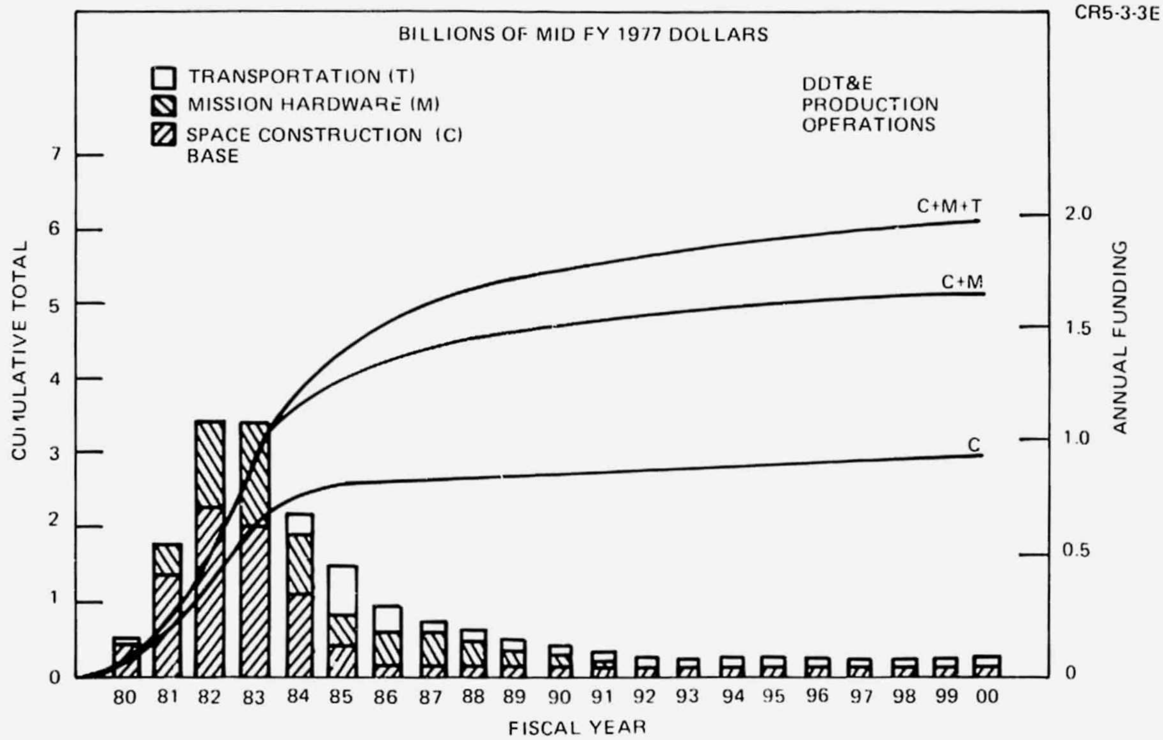

Figure 8-26. Direct-Growth Option Cost

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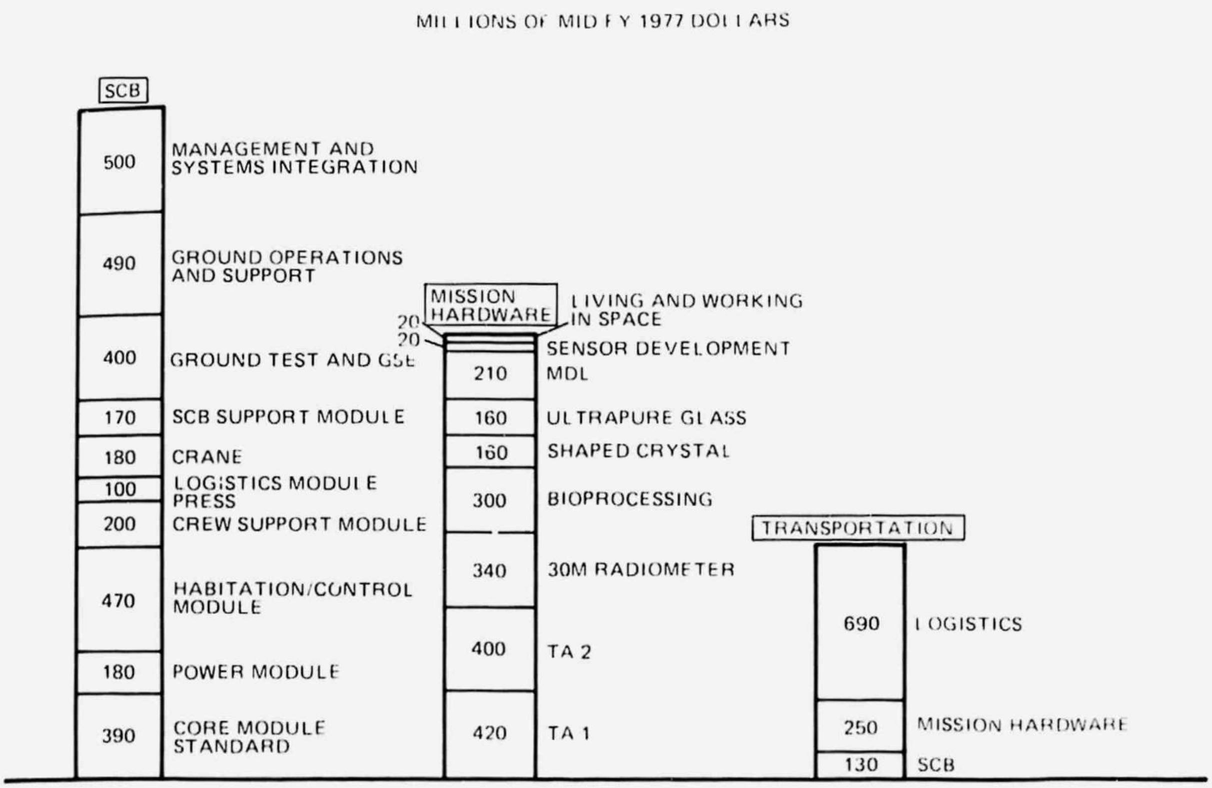

Figure 8-27. Direct Growth Cost Breakdown

Table 8-2

PROGRAM OPTION
COST COMPARISON

Option	Space Construction Base	Mission Hardware	Transportation	Total
Strongback				
Shuttle-Tended Mode	400	640	420	1,460
Total With Growth	3,350	2,020	1,200	6,570
Single Launch				
Shuttle-Tended Mode	710	660	290	1,660
Total With Growth	3,240	2,040	1,020	6,310
Direct Growth				
Shuttle-Tended Mode	1,460	760	360	2,580
Total With Growth	3,100	2,030	1,070	6,200
Permanently Manned	3,060	2,030	860	5,950

Cost in $Millions

of the option becomes more autonomous because there is less hardware duplication as the autonomy increases.

The cost of the SCB in the Shuttle-tended mode increases from $400M for the strongback to $1460M for the direct growth. This reflects the increase in the amount and complexity of the modules forming the base. On the other hand, the total cost of the SCB (including growth) is greater for the strongback ($3350M) than the direct growth ($3100M) with the single launch in between. This reversal of cost difference reflects the fact that the final SCB has almost the same configuration for each of the options. All the direct growth modules are used as is for the permanent station but some of the single launch (and still more of the strongback) modules need to be augmented and replaced to form the permanent station, thus driving up the total SCB cost.

The mission hardware for the Shuttle-tended portion of the options also increases from the strongback option ($640M) to the direct growth option ($760M). Even though the objective elements fabricated in the Shuttle-tended portion of these options is the same (TA-1 and 30m radiometer), the tooling for fabricating these items is considerably more sophisticated in the direct growth than the strongback option. The direct growth Shuttle-tended option uses the complex universal truss fabrication and assembly jig for constructing the TA-1. It also has larger, more versatile composite tube fabricating capability. Both the strongback and the single launch options fabricate the TA-1 without benefit of the universal truss fabricating jig. They, however, have simpler modules for truss assembly and tube fabrication. The strongback configuration contains austere, minimal capability tooling, and the single launch is slightly more complex.

When the mission hardware for the three options is expanded for the remainder of the objective elements (TA-2, space processing, sensors, etc.), the final total cost for mission hardware is about the same for each of the options. The strongback and single launch options require additional expenditure compared to the direct growth option because the universal truss jig is added to them. However, the total cost for the mission hardware does not show the same reversal of trend (i.e., the direct growth now being less costly than the strongback) shown by the SCB modules. The SCB showed the reversal because the final SCB configurations for all the options has the same capability. However, the mission hardware does not have the same final capability. The direct growth option retains the more sophisticated tooling it originally had while the other options still have their somewhat lesser capabilities.

The transportation cost for the Shuttle-tended portion of these options varies from $290M for the single launch to $420M for the strongback which represent differences in Shuttle flight requirements. The strongback has a longer period of time in the Shuttle-tended mode because of the smaller crew size and the less sophisticated equipment used to build to TA-1 and 30m radiometer. Approximately 1-3/4 years, at one launch per month (total 22 launches), are required before starting to build the permanent configuration for the strongback. The single launch option requires only 1-1/4 years in the Shuttle-tended

mode at one launch per month (total 15 launches) before starting to build to the permanent configuration. The direct growth requires about 4 mo longer or 1-1/2 y (total of 19 launches) because more modules are launched and the power module is not available as early as in the single launch. The transportation cost for the total program reflects not only the variation in cost during the Shuttle-tended modes but also that the direct growth requires only three launches to deliver the new modules required for the permanent station; the single launch requires five; the strongback requires seven. The launches required for mission hardware and logistics is the same for all the options once they reach permanent configuration.

The following conclusions may be drawn based on the cost studies of the configurations analyzed during Part 2 of the SSSAS:

1. The use of a Shuttle-tended mode of operation which later grows to a permanently manned station can lower the annual funding requirements compared to a program using only a permanently manned station, but only for the first few years of the program.
2. However, the total cost of the program, including the growth required to address all the objectives, is higher for the options that use the Shuttle-tended mode than for the options that use only the permanently manned station, and the peak annual funding is higher for the Shuttle-tended cases.
3. The increased cost of the Shuttle-tended options is due to the large increase in Shuttle flights required for the sortie mode operation, and the SCB hardware augmentation/replacement necessary to transition from the Shuttle-tended phase to the permanently manned phase.